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# PLANNING OF GEOTHERMAL DRILLING PROJECTS

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## ABSTRACT

Drilling is one of the most critical parts of any geothermal project. The cost of drilling forms a significant proportion of the overall project cost, especially in the early exploration stage where the project risk is greatest. The cost of wells varies significantly between projects, companies and geographical regions. The reason for this is not fully known, however, in addition to geological reasons, factors such as type of drilling contract and project preparation is likely to have significant impact.

This paper discusses the major factors impacting the preparation of drilling projects. It provides an overview of the procurement and contract issues and is aimed to stimulate project managers to consider various options during the planning of geothermal drilling projects.

## 1. INTRODUCTION

Drilling is one of the most critical part of any geothermal project. The cost of drilling forms a significant proportion of the overall project cost, typically 20-50%, but at the exploration stage, when the project risk is at its highest, the drilling cost is dominating (Pálsson, 2017).

Drilling risk itself is also a significant part of the project risk. In high temperature fields, average well output might be around 5-7 MW whereas output of each well can range from 0-40 MW. Therefore, it is important to focus on the planning of drilling works during the preparation for geothermal projects as it is one of the key aspects determining if the project is successful or not.

In general, the drilling industry is at the same time very conservative as well as always seeking ways of improving efficiency and the economy of the operation. It is often said that drillers don't want to change what works. The practice of drilling varies between different geothermal countries. Some bigger geothermal companies prefer to own their own rigs and crews whereas other companies prefer to tender the drilling operation. In countries with significant oil operation, such as the USA and New Zealand, similar drilling practices are applied in geothermal as in oil and gas drilling whereas other countries like Iceland have developed drilling practices that are focused on geothermal drilling.

This paper presents several key issues that are critical to consider when planning geothermal drilling projects. The author of this paper has been involved in geothermal project preparation for Landsvirkjun, the national power company of Iceland, for almost 20 years and has been involved in drilling of over 30 exploration wells in 5 geothermal fields, as well as advised on drilling operation in several continents.

The information provided in the paper is based on the experience and opinion of the author but not of Landsvirkjun.

## 2. DRILLING FOR GEOTHERMAL PROJECTS

In geothermal exploration, drilling is used for different purposes. Shallow drilling can for example provide indication about temperature gradient and information about groundwater flows that is required for environmental studies and to gather cold water for drilling, cooling and camps. Shallow drilling requires small rigs, limited civil work preparation and few workers and the preparation can be limited.

Prior to drilling full size deep wells into the reservoir, it is possible to drill a so called "slim hole". Slim holes are deep enough to enter the reservoir and allow logging equipment to measure temperature and pressure but have smaller diameter than full-size wells and have therefore limited capability to flow reservoir fluid to surface. This approach allows using smaller drilling rigs than required for full size wells with lower cost and smaller footprint and can be suitable to prove that a geothermal system exists underground, e.g. if there is a doubt about the interpretation of resistivity measurements. Information from the slim holes can also be used to improve the design of the full-size wells to follow. The drilling rig must be large enough to allow installation of BOP, which limits the selection of rigs. Landsvirkjun has core drilled several wells for that purpose in the outer boundaries of Krafla, Gjástykki and Theistareykir geothermal fields with a conventional coring rig and a wellhead valve with a diverter that was designed specifically for that purpose.

Drilling of deep full size geothermal production wells can be divided into four categories, depending on the stage of the project, as described in Table 1. The goals of the drilling project can be different, depending on the stage of the project. For example, the first wells are about proving the resource and are typically drilled with limited budget each whereas the wells at later stage are to gather as much steam as possible and therefore, it can be easier to justify more expensive wells, deviated and wider diameter. It should be noted that wells will be drilled throughout the lifetime of the geothermal plant to maintain steam flow as production from individual wells will decline with time. That reduction in productivity is natural and can be caused by decline in reservoir pressure, decline in pressure near the well, scaling or another flow restriction in the formation or in the well, due to corrosion or another factor causing friction, due to enthalpy changes or all the above-mentioned factors. Information from all previous wells is used to design each new well. Therefore, all wells, no matter what stage in the lifecycle, should

TABLE 1: Comparison between the characteristics of geothermal production wells, depending on when in the project lifecycle they are drilled

| Type | Stage | Purpose | Consideration |
|---|---|---|---|
| **Exploration** | Early feasibility | Typically, 1-4 wells to prove existence of geothermal system, measure temperature and pressure and analyse fluid properties. | Normally funded by equity funds or grants prior to project being bankable. Locate wells close to centre of field, often (low cost) vertical. |
| **Appraisal** | Late feasibility | Provide up to 50-70% of steam to prove field capabilities to confirm project is bankable and allow decision. | Project may or may not be bankable – drill out from centre of field. |
| **Production** | Construction | Gather remaining steam required to start of power plant at full load. | Typically, deviated wells from existing platforms – consider steam gathering system. |
| **Make-up** | Operation | Meet decline in well productivity, typically 1-4% per year. | May be more economical to group into drilling more than 1 well at a time. |

be considered exploration wells and used to gather as much information as possible about the reservoir characteristics.

It is also worth mentioning re-injection wells. The primary purpose of them can be either environmental reasons, i.e. to dispose separation water and condensate water (brine) or to provide reservoir pressure support. It is common to try to minimise the cost of re-injection wells as much as possible, even use wells that have failed to meet the criteria of production wells and often that can be very successful.

## 3. PLANNING OF GEOTHERMAL DRILLING

There are many issues that must be considered during planning of geothermal wells and many knots to be tied for a drilling project to be successful. This chapter will discuss a few critical issues.

### 3.1 Scheduling

The process from a decision to spudding can be up to one year (Figure 1). Apart from the permitting process, not only does it take time to sign a contract with a drilling contractor and have the drilling rig to the site but many essential items for geothermal well construction have a very long lead time. It can take up to 12 months to provide an expanding gate master valve and casing pipes typically have lead time of 3-9 months. Availability of drilling rigs and special items and equipment is highly dependent on the situation in the drilling market, affected by factors like oil price.

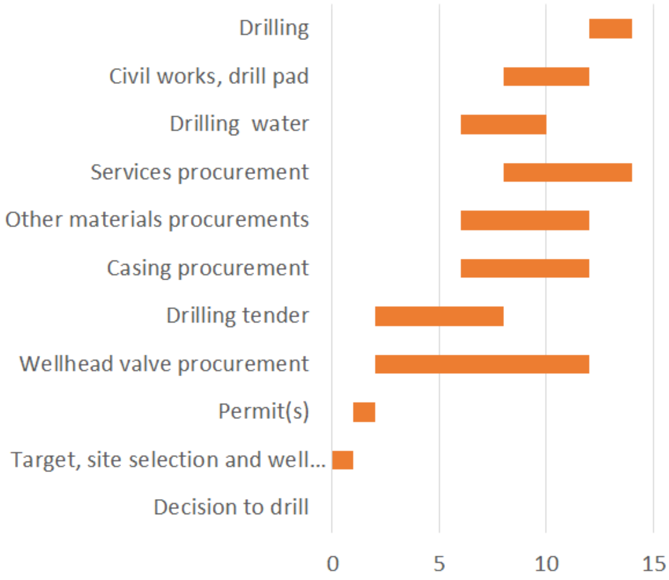


FIGURE 1: Duration of main work items and typical lead times for geothermal drilling

It is the experience of the author that the time required for the civil works, such as making suitable access roads, drill pads, drilling water and waste water treatment are commonly underestimated. These items are often depending on seasons. In the most extreme cases, geothermal companies have paid day-rates for drilling rig and crew for several months while road, bridge or drill pad construction has been delayed. In another case, drilling operation was delayed for several months as draughts had dried up a lake that was supposed to be the source for drilling water.

Drilling of a typical 2500 m deep directionally drilled well with an 8-1/2” production zone can take from 30 to 170 days, including rig mobilisation. In Iceland, it is common to assume 45 days whereas in other countries, geology, complex rig mobilisation, delay in delivery of items and services, and other factors can cause the work to take longer. Figure 2 presents the drilling progress of well HG-1, drilled by Iceland Drilling Company for Landsvirkjun in the Hágöngur Geothermal Field in central Iceland in 2003 (Jónsson, 2005). In this case, the well had been predrilled to 100 m before the main drilling rig arrived to site. The drilling progress was very good but at the end significant thermal-cycle stimulation was required to ensure sufficient permeability (Flores, 2005).

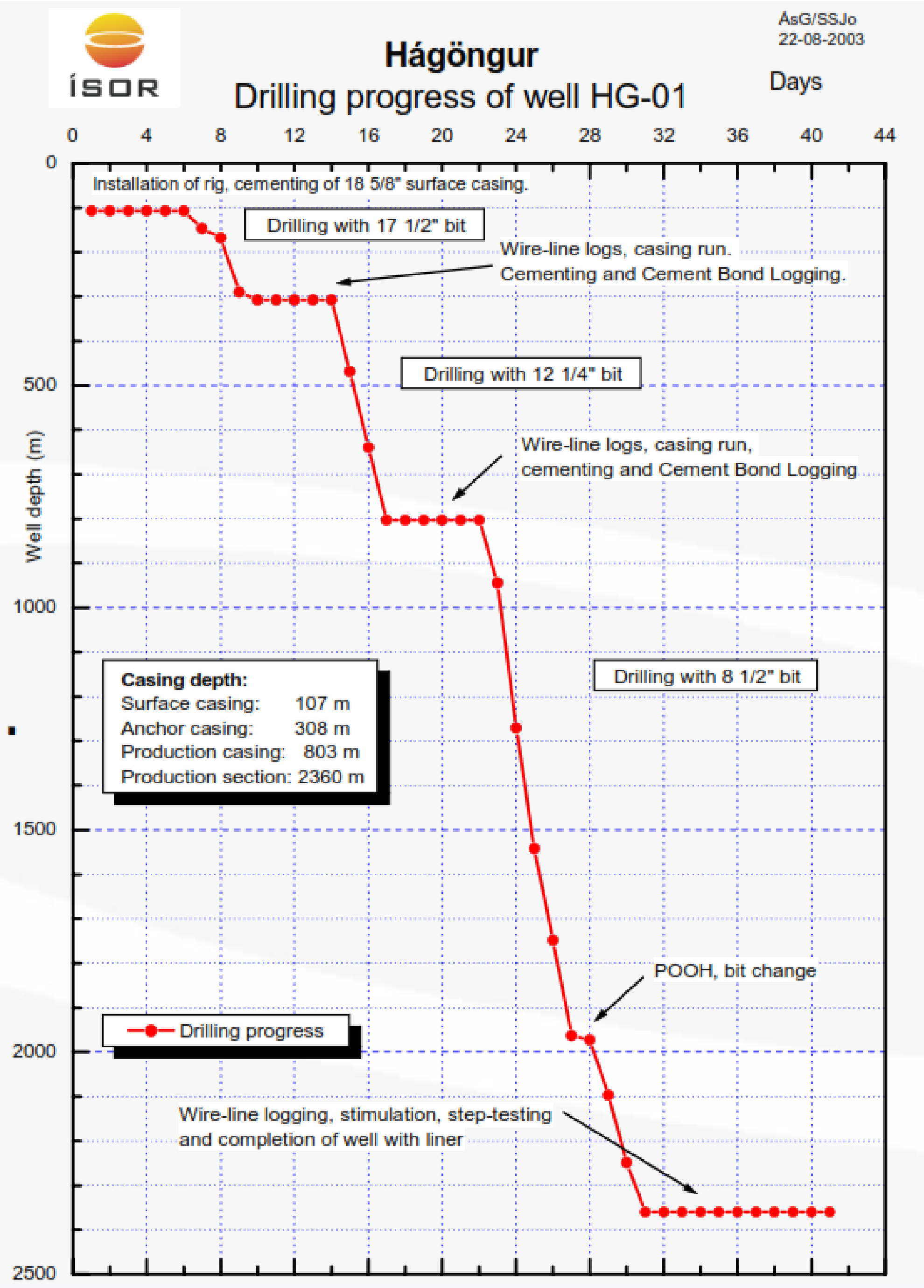


FIGURE 2: Drilling progress for well HG-1 in Iceland

### 3.2 Rig selection

It is important to consider the selection criteria for rig capabilities very carefully. The key parameters are determined by depth of the hole, well diameter, casing design and anticipated pressure conditions in the well. These will affect the capacity of mast, drawworks, rotary drive, pumps, mixing tanks, cementing units, BOP etc. It is common to spec the rig sufficiently large to allow handling of all possible events that can occur. The day-rate of a large rig may not be that much higher than for a smaller rig, however, everything becomes more expensive, mobilisation taking longer, fuel consumption greater, rig foot print larger etc. The risk and cost should be compared to find the optimum solution for each case.

In many countries, it is common to see "million pound" drilling rigs, i.e. with a mast that can sustain hook load over 500 tonnes. However, in Iceland, over 200 high temperature geothermal wells have been successfully drilled with rigs with hook load less than 220 tonnes. Loss in hole events do occur but are not more common than in other countries.

Icelandic companies have in the last decades applied stricter requirements for inspection and certification of rigs, equipment and drill pipes and that has significantly reduced the risk of downtime and losses.

It is very convenient to request modern rig instrumentation and data logging system with a good internet connection. It helps greatly for understanding the drilling conditions and can save significant traveling cost for experts and advisors to the site, and helps decision making. It is also helpful to operate an internet based project website to ensure efficient flow of information between all parties involved in the drilling operation.

### 3.3 Environmental impact of geothermal drilling

As the first exploration wells are often drilled prior to the environmental and social impact assessment of the overall geothermal project, the impact of drilling often receives less attention. However, if the environmental management is not sufficient, the following project acceptance and permitting process can be more difficult. Among environmental factors that must be considered are:

- Access and disposal of up to 40-60 l/sec of drilling water and possible impact on ground water;
- Handling and disposal of drill cuttings;
- Transportation and storage of fuel, typically 200-300 tonnes per well;
- Foot print, up to 10,000 $m^2$ and impact on soil, vegetation and wildlife; and
- Noise, traffic and other impact on society.

Various mitigation measures are available that should be considered, e.g. power the drilling rigs with electricity from the grid that will minimise noise, traffic of fuel trucks and risk of groundwater pollution and might also result in significant cost savings.

### 3.4 Auxiliaries

Apart from the drilling specific items, various other actions must be considered, such as construction of roads that can carry all traffic that is required for the operation. This includes long and heavy trucks that may require improvements to existing facilities, bridges reinforced, turning curve shaped and the steepest slopes avoided.

It may also be difficult to find suitable lodging for the drilling crew and worth considering minimising the number of people needed at site to minimise lodging requirements. Typically, installation of a work camp may cost up to $20,000 per person.

Other items than can considered in this context are access to drilling water, handing of drilling fluid, and disposal of geothermal fluid from flow testing.

## 4. PROCUREMENT AND CONTRACTS

As stated before, planning of geothermal drilling is complex and involves works, services and material from many different parties. Different companies have different policies about how to procure such projects but it typically requires around 10 main contracts:

1. Engineering design: Design of well and wellhead.
2. Civil works: Construction of roads, drilling platforms, water supply, cuttings handling etc.
3. Wellhead procurement: Master valve, operating valve, side valves, fittings, pipes etc.
4. Wellhead installation: Mechanical works, drilling cellar, borehole shed, silencer etc.
5. Casing pipes procurement.
6. Casing equipment: Centralisers, casing hangers, cementing tools etc.
7. Well logging services: Logging truck, tools and logging specialists.
8. Drilling services: Directional drilling, casing installation, cementing, mud logging etc.
9. Drilling supervision.
10. Drilling works. Rental of rig, crew and drilling tools.

The drilling works contract is normally around 50-70% of the overall project cost, depending on contract type, responsibilities and what is included. The sections below discuss some key issues related the procurement of drilling works.

### 4.1 Drilling contracts

Different geothermal companies have several different approaches towards drilling works.

- Own rigs and crew;
- Own rigs but tender out the operation; and
- Tender out works to drilling contractor.

A few larger geothermal companies have opted to have their own drilling rigs and operate them with own employees including all support. The main benefits are that the drilling is available and at the site when needed, the rig and its equipment has been specified for the conditions at the site and the crew is experienced in the site-specific conditions. The main disadvantages are the cost of capital and labour when the services of the rig are not required, cost of spare parts, maintenance facilities etc.

Assuming it takes 45 days to drill each well, including rig mobilization, and that total maintenance and inspection time is 50 days per year, each drilling rig can drill up to 7 wells per year. Companies that decide to own and operate their own drilling rigs must recruit and/or have access to 3-4 shifts of crew or 20-30 persons, maintenance team and administration team, in total at least 30-40 skilled staff for the first drilling rig. Therefore, to justify owning a drilling rig, the company must drill at least 3-4 wells annually for several years, that is for reasonable usage of equipment and manpower.

Among companies that own their own drilling rigs is Enel in Italy (Razzano, 2015). Enel has produced geothermal power for over 100 years and currently owns around 900 MW of installed power in around 30 geothermal power plants in Tuscany. The company has a large drilling department with several drilling rigs, mostly for drilling activity in their geothermal fields in Tuscany, but also internationally. If assuming production decline of 2% on average per year, and 5 MW per well, the need for make-up wells is around 4 wells per year on average, in addition to work-over operations, injection wells and exploration wells for new areas.

Among other companies that have opted to operate its own drilling operation is GDC in Kenya, that has great plans for power generation (Omenda, 2015) and EDC in the Philippines that owns and operates 1500 MW in several locations.

The company Star Energy in Indonesia is an example of a company that opted to own its own drilling rig for the development of the Wayang Windu geothermal field but as the drilling schedule was not continuous, the company decided to tender out the drilling works (Smillie, 2010). The main reason for buying the drilling rig was that it took 2 months to transport the rig from harbour to site through tight roads in the highly populated area.

Most common in many geothermal countries, like Iceland, New Zealand and the USA, is to tender out the drilling works. For tendering drilling works, two fundamental issues must be considered:

1. Integrated drilling services or "conventional" drilling services.
2. Day-rate contract, a meterage contract or a "hybrid-type" contract.

Traditionally, it is considered "*conventional*" that the drilling contractor only provides a drilling rig with the basic equipment and crew and gets paid a rental per day. The operator must procure services of specialized companies for most additional services, such as directional drilling, casing run, cementing, well logging, geological logging etc. It is even common that the operator pays for fuel, rent special equipment like drill string tools, BOP, drill bits etc. This is based on over 100 year tradition from the oil and gas industry. In this arrangement, up to 10 experts, including cementing crew, logging crew etc., are waiting on site for long periods of time. The cost of these experts can add up to $20.000/day or over $1 million/well.

In countries with greater tradition for geothermal drilling and less tradition for oil and gas drilling, contractors specialised in geothermal drilling have been established, like Iceland Drilling (Jardboranir), MB Century in New Zealand, ThermaSource in the USA and a few contractors in Turkey. These companies have specialized in geothermal risk and are therefore able to handle great part of the responsibility, even in high temperature fields. In Iceland, it has been the standard practice that the contractor has specialized crew able to drill, run in casing and cement and recently the Iceland Drilling company developed the capability to provide directional drilling services as well. Therefore, the drilling contractor, not the operator, is responsible for the time schedule of the operation and therefore carries the cost of service providers waiting on site. This is often referred to as *integrated drilling services*.

For the "conventional" contractual arrangement, it is most common to use a contract that is basically hourly or daily rental of rig, rig equipment and crew, called a *day-rate contract*. The payment scheme can have several items, such as with or without engines running (more or less wear and tear), in operation or in stand-by mode, with or without crew etc. Another less common type of contract is to pay per unit depth of the well or socalled *meterage* or *footage contract*. The price structure for this type of contract is very simple. Most of the responsibilities are in the hands of the contractor which is not only taking the construction risk but also the geological risk. It is therefore suitable for contractors that have significant knowhow to be able to put a price on the risk they are taking and for operators that do not and prefer to transfer that risk. This type of contracts is most common for relatively shallow wells and lower temperature geothermal fields. Such contracts can often be considered as turn-key contracts. The comparison between day-rate contracts and meterage contracts is summarised in Table 2.

It is most common to base drilling contracts, both for *day-rate contract* and *meterage drilling contracts* on standard forms from the International Association of Drilling Contractors, IADC. IADC has issued these contract templates over many decades and they are well known by international contractors and operators.

Landsvirkjun, the national power company in Iceland, and Reykjavík Energy have developed and successfully used over two decades a special form for integrated drilling services that covers the benefits of both day-rate and meterage drilling contracts. The drilling contractor is paid a lump sum for rig mobilization, inspection of drilling tools and providing all tools required for the works. The contractor is paid per meter for drilling, casing run and cementing, unit prices for volume of materials used, such as cement, mud additives, casings etc. If the drill bit gets stuck for lengthy period, time during logging and other time that the operator requests is paid per unit time charge. This type of contract, that is a mix of day-rate, meterage and lump sum unit prices is referred to as *hybrid drilling contract*.

A critical item, connecting risk and return, is a risk sharing clause for the case of loss in hole up to a certain limit, typically $200.000 - $1.000.000. This clause ensures that even though the contractor benefits from drilling at high speed, he is also penalised for drilling too fast or without full care. It is very important to set the limit not too high as it may put many contractors off if the risk is too high.

The hybrid drilling contracts favour highly skilled and experienced contractors that are able and willing to take on risk but are not recommended for less experienced contractors.

TABLE 2: Comparison between meterage/footage and day-rate contracts

| **Meterage/Footage contracts** | **Day-rate contract** |
|---|---|
| Drilling contractor is paid per depth unit. | Drilling contractor is paid for <u>rental</u> of rig and crew per time unit, day or hour. |
| Meter price may alter with the specified formation, depth or diameter. | Day-rate will vary depending on extent of operation, e.g. pumps on, pumps off, with crew, without crew etc. |
| Meter price includes all <u>special tools</u> required for the drilling, even though the contractor may have to rent those for the drilling works, incl. BOP, fishing tools, mud motor and other BHA items. | Operator pays rental for all <u>special tools</u> required in addition to the basic equipment that come with the rig. |
| Meter price will include all <u>routine supplies</u> for the drilling operation, including fuel. | Operator pays cost of <u>routine supplies</u> for the drilling operation, including fuel. |
| Meter price normally includes <u>material</u> such as casing, cement, mud, cement and mud additives and wellhead. | Operator pays all <u>material</u>, such as casing, casing equipment, wellhead, cement, mud etc. |
| Meter price normally includes <u>special services</u>, such as rig- and drill string inspection, casing services, cementing cervices, mud engineering, mud logging, directional drilling, well logging and wellhead installation. | Operator pays all <u>special services</u>, such as rig- and drill string inspection, casing services, cementing cervices, mud engineering, mud logging, directional drilling, well logging and wellhead installation. |
| Drilling contractor is given broad control over how to do the work. | Representative of the operator at site (company man) instructs how to do the work. |
| Hence, the risk of unexpected delays along with other liabilities is on the contractor and not on the operator except in case of formation problems. | Hence, the operator carries the main responsibility but the contractor is liable for failures on the rig causing down time. |
| **Typical rate is $1000-$2000 per meter** | **Typical day-rate is $25.000-$50.000** |

### 4.2 Service contracts

Many service contracts must be made that will not be discussed in details here. They are more conventional, typically based on day-rates. Day rates by international service companies that also service the oil and gas companies often range from $1500 to $2500 per day, in addition to rental of equipment and provision of special materials. Occasionally, these companies are willing to offer lower fees as the geothermal industry is not able to pay as high a premium as the oil and gas industry. It should also be considered to request services from experts that have experience from geothermal. The key service contracts are the following (Miyora, 2015):

- Well logging;
- Geological logging;
- Mud engineering;
- Mud logging;
- Directional drilling;
- Running casing; and
- Cementing.

## 5. COST OF DRILLING

The author of this paper has for the last decade or so explored widely the drilling experience of most major geothermal operating companies in the world. Most common cost for drilling a 2500 m well with an 8-1/2" production zone and directionally drilled with 30° angle is $7 million. However, this cost can be as low as under $4 million in Iceland, Romania and Turkey and up to $15 million in Japan. If incidents occur, cost can easily escalate and several recent cases in Iceland, New Zealand and East Africa have resulted in cost exceeding $15 million.

The main reason for this difference is the number of days for drilling and rig mobilisation, ranging from 45 on average in Iceland to over 100 days in East Africa. Other reasons include differences in environmental requirements, geological formations etc. However, it is the belief of the author that drilling works under day-rate contracts will take longer. It is also his belief that the progress is higher when integrated contracts are applied, where the drilling contractor is responsible for cost of the sub-contractors and it is in the benefit of the drilling contractor, as well as the operator, that the drilling progress is as high as possible.

Landsvirkjun hast just finished drilling 8 production wells for the new geothermal power plant in Theistareykir, most directionally drilled and 2500 m deep. An integrated hybrid-type drilling contract ensured average well cost to be below $4 million. The experience from Iceland is that even though day-rates can be quite high, the progress of the drilling works has ensured the overall well cost to be among the lowest in the world.

## 6. CONCLUSIONS

It is difficult to estimate the cost of each geothermal well due to uncertainty about the exact location of the target, the type of formation that will be drilled through that will affect the rate of penetration and possible delays due to either loss of circulation or borehole collapse. The cost of geothermal wells depends mostly on the number of days it takes to drill. This is obvious in "conventional" day-rate contracts but the pricing of meterage or hybrid contracts will also reflect the expectation of the contractor on how many days he must pay salaries for his crew and sub-contractors.

Due to the high daily cost, it is justifiable to pay for expensive equipment to enhance the rate of penetration and reduce the risk of having to wait for experts, equipment or material to arrive on site. Most importantly, it is worth spending significant time in planning and preparation, prior to the start of drilling, e.g. "drill on paper".

Selection and design of drilling contract can affect how qualified and experienced drilling contractor will have the best offer, reduce the risk of low drilling progress and great cost overruns. Most geothermal operators don't drill many wells every year whereas drilling contractors do. Therefore, the drilling contractors are in a good position to carry part of the risk.

Financiers are encouraged to have experienced experts to perform due diligence on drilling preparation to ensure there are no gaps in the project plan, that the specifications for drilling equipment are correct, that an optimum contract scheme has been selected, that risk allocation is in balance and that allocation of responsibilities is clear and without gaps.

Drilling projects are by nature complicated – however, the planning should have the aim to keep it as simple as possible!

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