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Geothermal Capacity Building Program Indonesia - Netherlands

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Small scale direct use of geothermal energy in sedimentary basins using slimhole drilling techniques, Indonesia

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1 INTRODUCTION

1.1 GENERAL

Indonesia's industrial sector is growing rapidly. It is the biggest contributor to Indonesia's GDP growth over the past years. According to World Bank statistics the sector has seen a steady growth of about 5% per year since 2010. Some of the main industrial export products of Indonesia are mining products, palm and coconut oil, textiles, paper and electronics. The increase in industrial production results in an increasing demand for energy. From 1990 to 2010 the total demand for energy in the industrial sector has more than doubled from 20 Mtoe to 45 Mtoe (Figure 1)

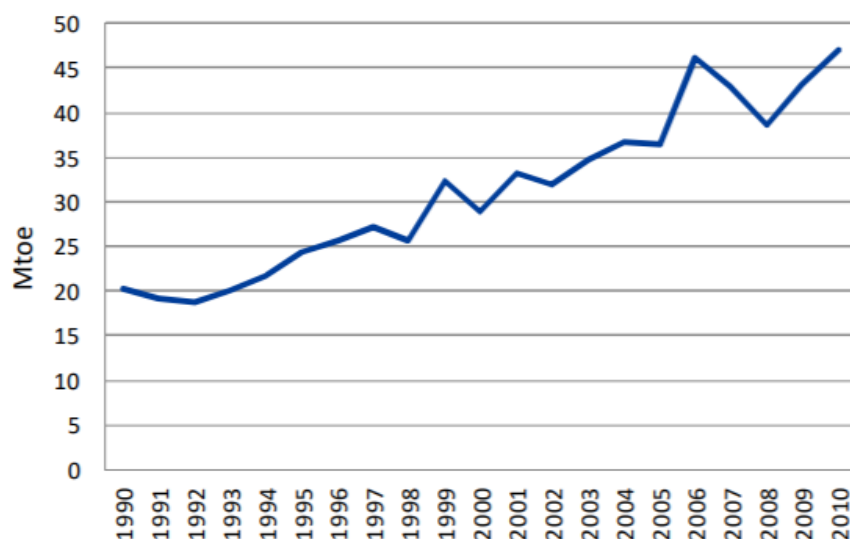


Figure 1 Yearly energy use of Indonesian industrial sector (source: Enerdata)

At the same time there is also a shift taking place in the source of the energy used in Industry. As shown in Figure 2, oil is being replaced by coal and natural gas. At the same time the total share of fossil fuels is increasing over the use of biomass as an energy source. The increasing reliance of Indonesia's industrial sector on fossil fuels is a risk to its competitiveness and endangers the climate change ambitions.

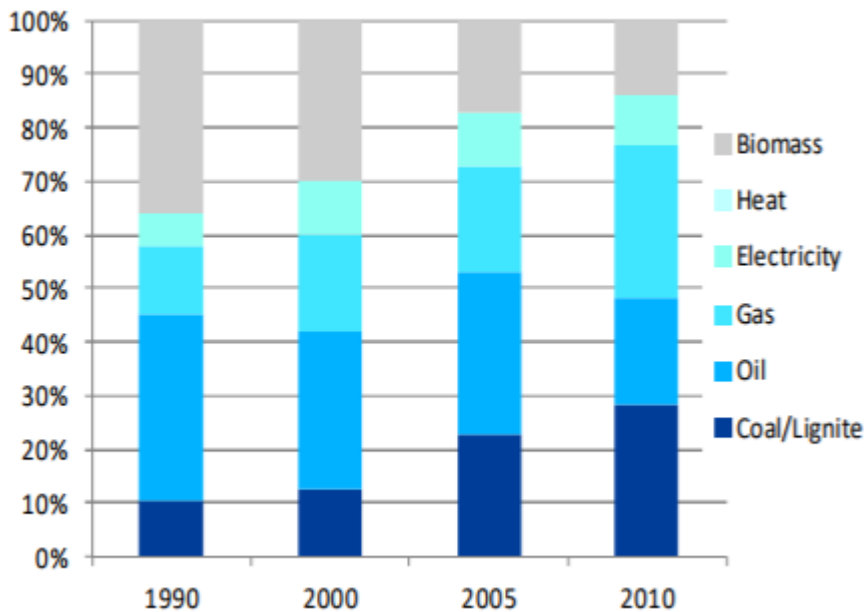


Figure 2 Industrial energy use distribution by source (source: Enerdata)

Even though Indonesia has one of the largest potential for geothermal energy in the world, it is remarkably absent as a source of energy for industry. In Indonesia, geothermal energy is synonymous with power generation from high enthalpy volcanic systems. These volcanic systems are commonly found in mountainous and therefore quite sparsely populated areas, while industrial centres are concentrated in the lowlands where there is lots of people and good transport infrastructure.

This does not mean that the idea of using geothermal heat for industry in Indonesia is without merit. It does however require a different approach to geothermal than the prevailing notion that geothermal is only viable in high enthalpy volcanic systems. It is here that some of the experiences of using geothermal heat from sedimentary geology, as practiced in The Netherlands, could be of use.

In general, drilling wells in sedimentary geology is done to extract oil, gas or drinking water. Extracting heat is less common but not unusual. In The Netherlands there are 13 projects that extract heat from sedimentary aquifers between 1-3 km depth, mainly for use in greenhouses. The downside of sedimentary geology compared to volcanic regions is that the geothermal gradient is generally lower. This means that much deeper and therefore more expensive wells are required to achieve the same production temperature. The upside is that the permeability of sedimentary layers are more uniform, reducing the drilling risks and the need for extensive exploration efforts. On top of that, many sedimentary basins have

been subjected to oil and gas exploration further reducing the need for additional surveys and exploration wells.

1.2 CONVENTIONAL VS SLIMHOLE WELLS

As there is no conversion efficiency in a direct-use application the potential thermal power output of a well is significantly higher than the electrical power output (in case of indirect use). The downside of a direct-use well is that thermal energy is much harder and therefore more expensive to transport than electrical energy. This means that the energy must be used locally putting a restriction on how much offtake you can realize.

As an example, let's take a conventional geothermal well in a sedimentary basin. It could easily produce a flow of 250 m³/hour. If this flow is cooled down by 50°C, the thermal output of the well would be about 20MW. In discussions we had with industry partners the demand was in almost all cases lower than 20MW. This leaves two options, pooling multiple users together or developing smaller wells (also called slim-hole wells). The challenge with pooling different users is that it becomes much more complex from an organizational perspective. All parties have to agree on the set-up and operation of the project. It is therefore worthwhile to look at the option of using smaller and cheaper wells to provide a suitable power output for a single user. This is the topic explored in this paper.

1.3 SLIM HOLE WELLS

Making these small scale geothermal direct-use projects feasible requires the smaller wells to also be cheaper compared to conventional geothermal production wells. Slim hole wells are already applied in oil and gas industry as well as in mining and geothermal exploration. As far as we know slim hole wells have not been used as direct heat supply for industry or other applications.

1.4 RESEARCH QUESTION

The main question we aim to answer is: Is the direct-use of geothermal heat in industry using slim-holes in sedimentary basins in Indonesia a sustainable alternative?

1.5 SCOPE OF STUDY

Most of the Indonesian industry is situated nearby the major cities in industrial estates. Most of these Industrial estates are located in the sedimentary basins. Therefore we focus on sedimentary basins in this study.

We searched for sedimentary basins on strategic locations where (direct) heat is demanded. With this information we investigated the possible market opportunities within the Indonesian Industry (Chapter 2). Based on this information we made a slim hole well design for a specific case (Chapter 3) and estimated the cost of slim hole well for both realization and exploitation phase (chapter 4). At chapter 5 the feasibility is investigated. Conclusions and recommendations can be found in Chapter 6.

Before starting this investigation we performed a literature review about the state of art of slim hole drilling worldwide and especially in Indonesia (Appendix 1).

2 MARKET OPPORTUNITIES AND CASE DESCRIPTION

2.1 INTRODUCTION

As described in previous chapters, we focus in this study on direct heat delivery for industrial processes, within sedimentary areas in Indonesia. To determine where potential customers are located, the sedimentary areas are mapped. In figure 9 a map of Indonesia is presented, with highlighted in yellow the sedimentary areas. This is a relative large potential area.

Within these areas we are interested in industrial estates in/near major cities, because there might be energy demands.

An estimation of cities located in sedimentary basins has been made, the potential cities are listed below (with ranking of population size, source: Wikipedia). For determining which cities are located in the sedimentary areas maps from the USGS and Badan Geologi KESDM (figure 3) are used, (literature list, documents 11 and 12).

Java

- Jakarta (1)
- Soerabaja (2)
- Bekasi (5)
- Semarang (6)
- Tangerang (7)
- Depok (8)
- South Tangerang (10)

Sumatra

- Palembang (9)
- Pekanbaru (13)
- Jambi (24)
- Bengkulu (35)

Bali

- Denpasar (17)

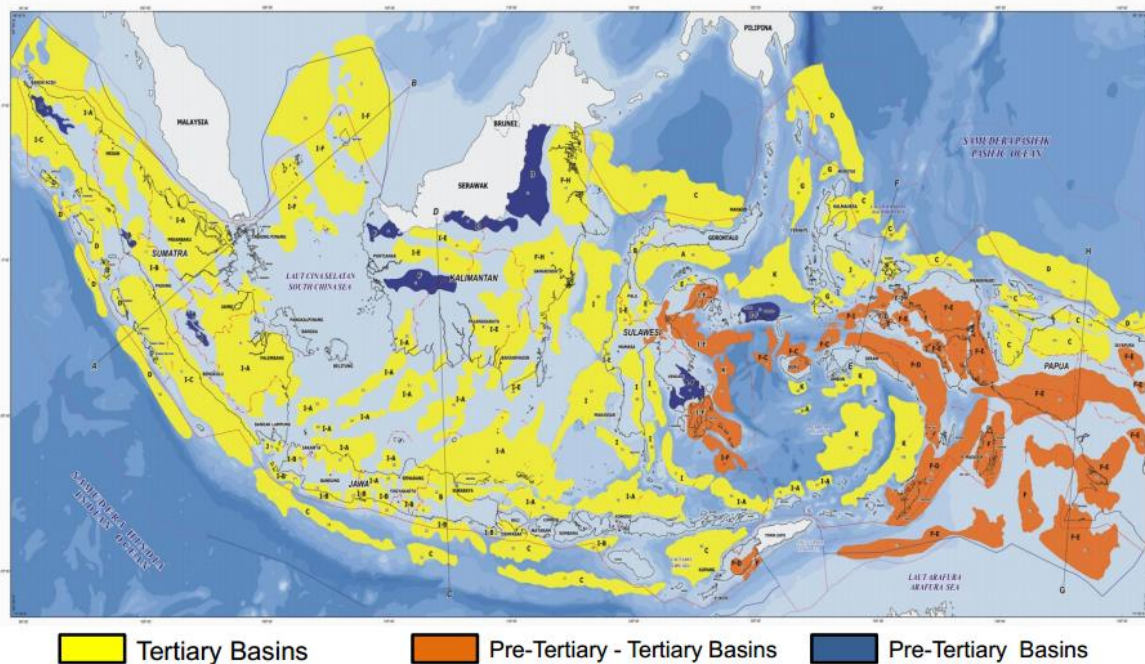


Figure 3: Sedimentary basins in Indonesia (Source: Badan Geologi KESDM)

The most and biggest cities are located at Java, the relative potential can be found there. Besides this, the most information of the Geology (temperatures, depths and Aquifer thickness) is available from Java within the Geocap (WP 3.0) project. This is the main reason we focus in this study on two industrial Estates located near Jakarta. These Industrial Estates are situated in the Northwest Java Basin. These industrial Estates are Jababeka and Karawang.

The following information is taken from the Geocap report “WP 3.01 Resource Assesment”, 31-01-2016, by ITB, Authors: S.D.H. Putra, N. Putri, N. Suryantini. The information has been modified.

2.2 THE ONSHORE NORTHWEST JAVA BASIN

The onshore North West Java Basin is situated in the northwestern part of the island of Java, the extent can be found in figure 4. The basin is known to host hydrocarbon resources the reserves of which has been confirmed through commercial drilling and exploitation activities by PT PERTAMINA, a state oil company (Suryantini, 2007). In the Jakarta area, in the Northwest Java Basin, two major Aquifers are situated, the Baturaja Aquifer and the Talang Akar Aquifer.



Figure 4, showing the areal extent of the onshore part of the North West Java Basin and the approximate location of the geothermal market target Karawang and Jababeka).

2.3 AQUIFER TEMPERATURE

The temperatures-at-depth at different locations has been mapped. With this information the temperatures at the center of Baturaja and Talang Akar aquifers at different locations are determined. Figure 5 and 6 show these temperatures.

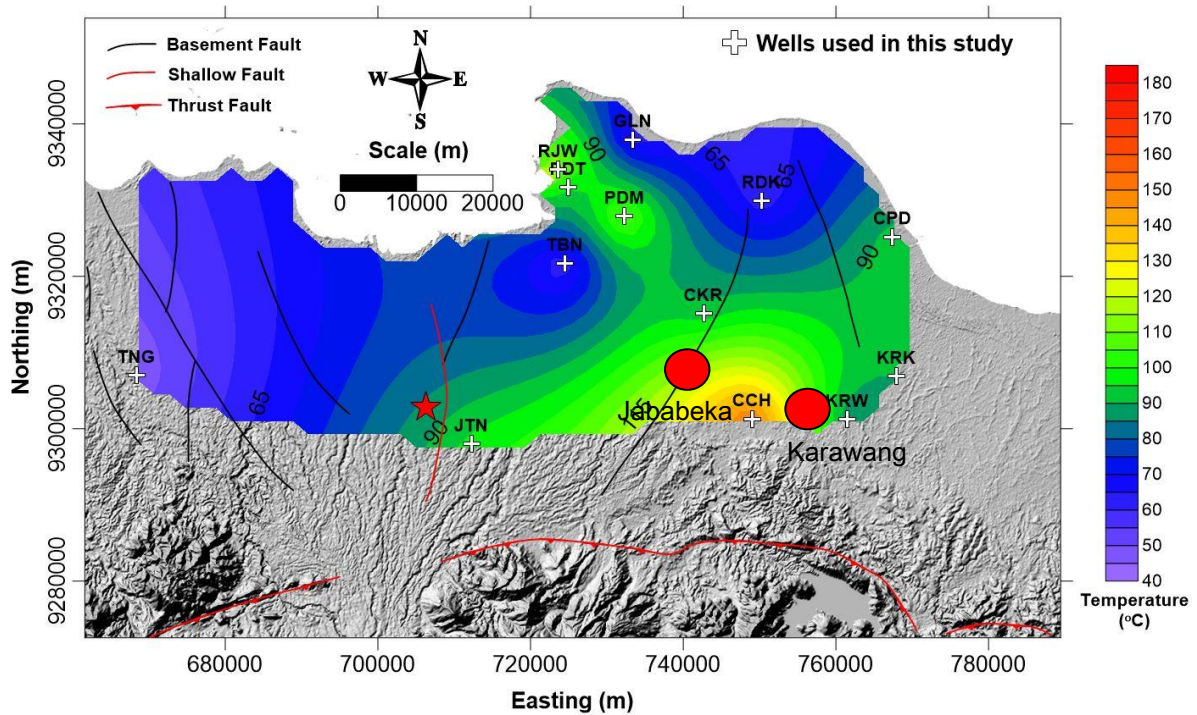


Figure 5, Map showing the distribution of temperatures within the Baturaja aquifer.

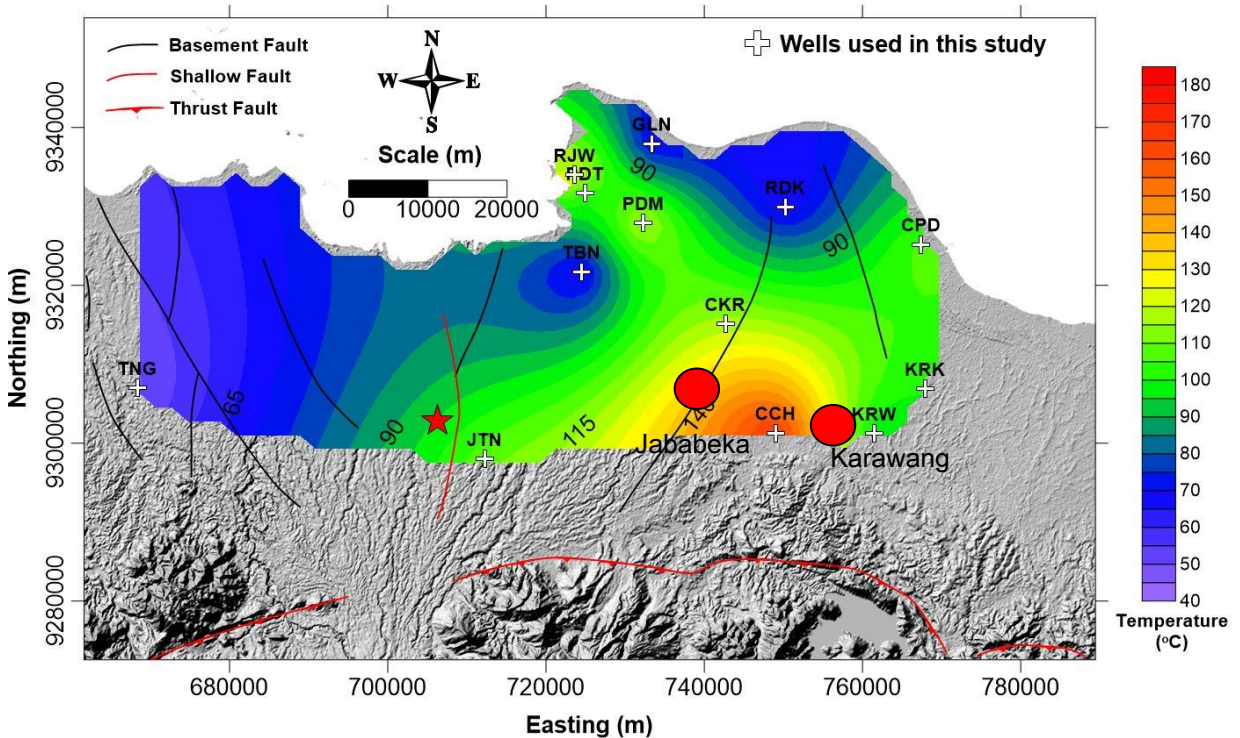


Figure 6, Map showing the distribution of temperatures within the Talang Akar aquifer.

2.4 AQUIFER DEPTH

The depths to the top of Baturaja and Talang Akar aquifers are calculated with the use of available soil information. The spatial distribution of the depth of the aquifers are represented in maps shown in Figures 7 and 8.

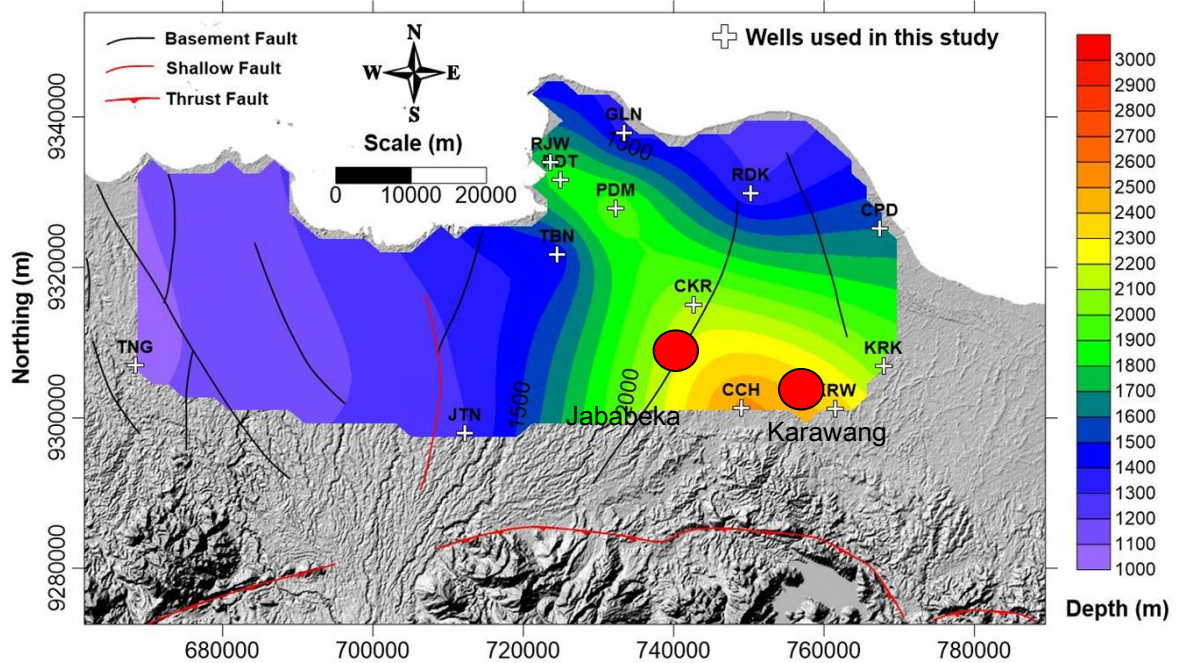


Figure 7 Map showing the distribution of depth to the center of Baturaja aquifer.

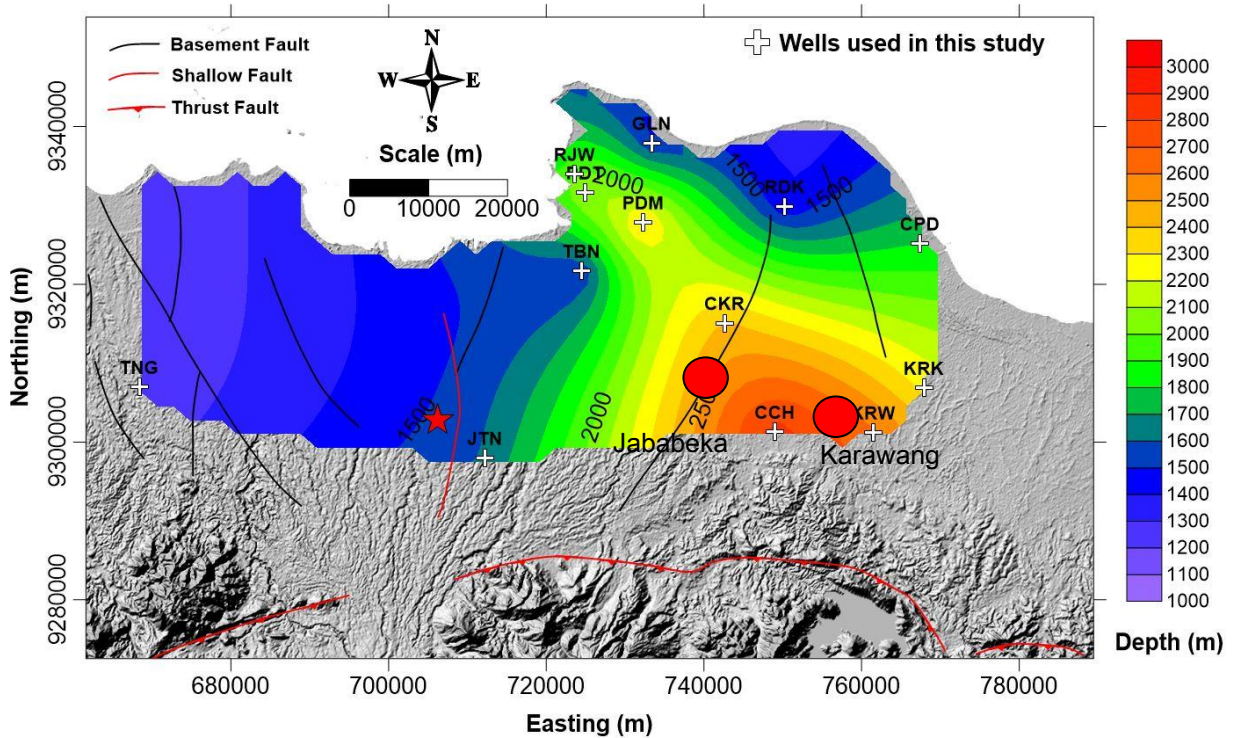


Figure 8 Map showing the distribution of depth to the center of Talang Akar aquifer.

The characteristics of both aquifers for the locations Jababeka and Karawang are summarized in Table 1.

Table 1: characteristics of potential aquifers in Jababeka and Karawang

Location	Aquifer	Depth	Temperature
		[meter below g.l.]	[°C]
Jababeka	Baturaja	2250	115
Jababeka	Talang Akar	2550	135
Karawang	Baturaja	2400	110
Karawang	Talang Akar	2700	120

2.5 MARKET OPPORTUNITIES

The following information is taken from the Geocap report “WP 3.02 Market Survey”, 24-01-2016, by UI, Authors: W.W. Purwanto, D. Supramono, reference: GEOCAP-20160124-REP-UI-WP3.02. The information has been modified.

Possibilities for direct use of geothermal heat

A selection of existing utilizations and other potential applications are characterized by the desired temperature levels are shown in Figure 9. The expected temperature range, which can possibly delivered by slim holes in Indonesia is marked in blue in the figure. There are even more applications which require a lower temperature than delivered directly with a slimhole. In the optimal scenario, processes can be cascaded.

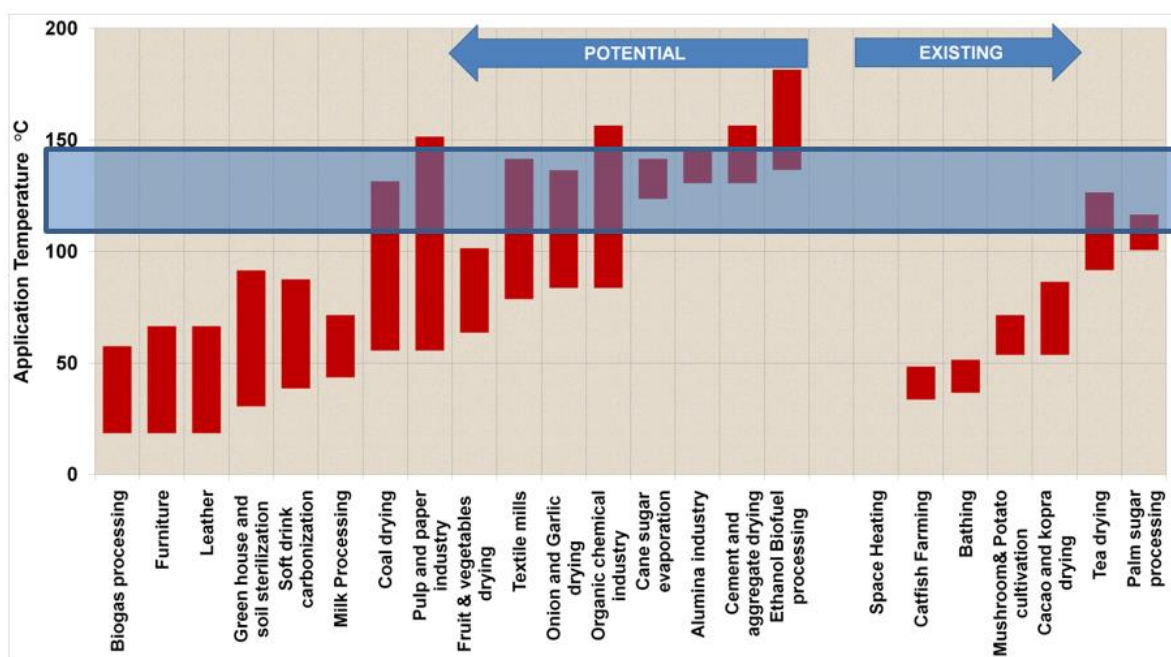


Figure 9. Potential direct users of geothermal heat and their applications

Industry in Karawang and Jababeka

For this study we have focused on present Industry in Jababeka. The following users in the industrial area of Jababeka are seen as practical potential users of direct use of geothermal energy:

- Paper Industry
- Food industry
- Consumer goods

The energy demands vary between the several potential users. An estimation of the thermal energy demands has been made and is expected to be between 5 – 10 MW thermal energy. The required temperatures has been determined between 55 – 135°C.

3 SLIM HOLE WELLS

3.1 INTRODUCTION

In paragraph 2.5 energy demand for typical industry in Jabakeka has been described. The basic principle is to use the geothermal heat directly for industrial purposes as paper and food process. The energy demands for these processes are relative low, when compared to an average delivery of a geothermal well used for generating electricity. Geothermal wells are maximized to generate an electricity production as high as possible. For the defined cases, the delivery of direct heat has been set at 80 m³/h of geothermal water. The goal is to make geothermal wells in the sedimentary basin which can deliver this amount of water, while the realisation costs as well as exploitation costs are kept as low as possible.

A similar concept of reducing costs has been investigated and applied in the oil and gas industry in the past. The urgency to cut costs for exploration of oil and gas was and still is high during times of relative low oil prices. Therefore the concept of slimhole drilling has been developed, which started in the 1920's. Multiple definitions for slim hole drilling are used, the main principle is making much smaller holes compared to traditional holes. The techniques for making slimholes has been improved by the years. Nowadays slimhole wells are a proven technology.

3.2 DRILLING TECHNIQUES

Most common used drilling techniques which are applied for drilling slim holes are diamond wire line-cored drillings and rotary drillings. In general, diamond wireline drilling is used for exploration, rotary drilling is used for making production wells (oil, gas) and can be downsized to cut costs.

For the application of direct heat in the selected areas of Jakarta, the most suitable drilling technique must be applied. Based on the performed research (reported in appendix 1) the most suitable drilling technique is rotary drilling. The main reasons are: The formation is not very consolidated, a relative large well diameter is required at the top of the well, to allow placement of the ESP. Both aspects can not be performed with wire line core drillings. For the design of the wells we therefore have focused on the rotary drilling technique.

3.3 DEFINING THE CONDITIONS FOR A SLIMHOLE WELL DESIGN AT JABABEKA

Based on the information gathered from the literature review (appendix 1), and aspects in chapter 2 the following conditions are defined below. In the next paragraphs:

- The slim hole well must be able to deliver (and reinject) water with a flow of 80 m³/h.
- The slim hole well must have a final drilling diameter of at least 6" or less to apply the smallest casings as possible. By doing this there is no possibility to apply a smaller casing string when drilling problems occur.
- We focus on the sedimentary basins of Jababeka, with an aquifer depth of approximately 2550 meter below ground level.
- The production well must be provided with a submersible pump, the premise is that the well is not self-flowing. This results in a relative high upper casing diameter in order to make space for the submersible pump.
- A relative small rotary rig must be able to perform the drillings. The maximum hook load is set at 100 tonnes. This hook load makes it possible to perform drillings with a maximum depth between 2500 – 2800 meter below ground.
- The slimhole wells are not deviated but true vertical, to keep it as simple as possible (to prevent problems as stuck pipes etc. and less expertise needed) as well as keeping the costs as low as possible.

Other aspects that are important for the design and drilling are listed below. These items however are not taken into account in this well design due too limited information of the geology on the location:

- Geology aspects (other than temperature in relation to depth)
- Water quality composition
- Information about known drillings risks, gas kick, risk of sandproduction, etc.

We do endorse the fact that these aspects could have a major impact on the feasibility. It was decided only to focus on the main goal to evaluate the slimhole technique considering small sizes and less complex drillings to reduce costs. The other aspects do both account for conventional drillings as well as for slimhole drillings and will imply similar design considerations. For any future demonstration projects these other aspects need to be taken into account!

3.4 HOW TO DESIGN A SLIMHOLE WELL?

The well design of a slimhole well is in general similar to standard geothermal wells and oil and gas wells. The amount of casings strings and the diameters are limited as much as possible for slimhole wells. The amount of casings strings are determined by the geological conditions, regulations and safety requirements. In general a well is made up of three casings, the surface casing, intermediate casing and production casing. The deepest (production) casing is in many cases, depending on the formation, provided with a screen (slotted liner) or perforated liner. The conductor casing provides the initial stable structural foundation for the borehole and serves as a support during drilling operations, to flowback returns during drilling and cementing of the surface casing. It also isolates shallow unconsolidated formations.

The surface casing prevents the borehole for a blow out. This casing must be closed with the BOP in cases of emergency. The surface casing must withstand high pressures. The surface casing also prevents for lost circulation and unconsolidated formations.

The intermediate casing is installed to isolate unstable hole sections, lost circulation zones, low pressure zones, and production zones. Sometimes the intermediate string is also used as production string, when a liner is placed below the surface casing.

In figure 10 the general terms for the casings has been given.

Typical Well Casing Diagram

(Not to Scale)

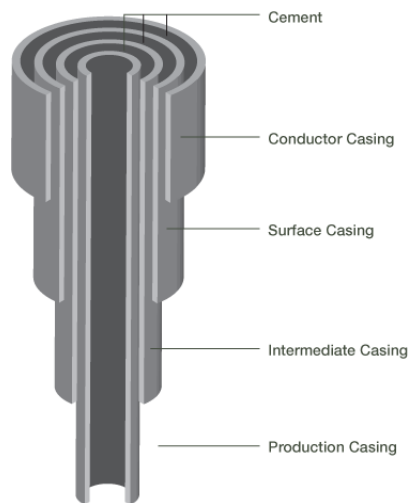


Figure 10: Example well casing diagram

The casings must be able to withstand the various forces to which the casings are exposed. These are not particular different compared to conventional oil and gas wells. The most important forces are burst, collapse and tension.

- **Burst:** the pressure inside the casing is higher than the outside pressure. A high burst pressure can be caused by gasses which are accumulated in the production casing, while the casing is closed.
- **Collapse:** the pressure outside the casing is higher than the inside pressure. This situation occurs during cementation of the casing, when the cement is outside the casing and not inside the casing. The density of the cement determines the collapse pressure.
- **Tension:** The weight of the total casing string is more than the steel can withstand.

The casing dimensions, such as the diameter, wall thickness/nominal weight, steel grade determine the strength of the pipe for burst, collapse and tension.

Safety regulations play an important role in casing design. One of the most important items is the depth of the surface casing and cementation (which is described by Finger et al., 1999). Once the minimum required depth is reached, casing will normally be run unless the formation is particularly fractured and broken. It is important to have competent sediments at the casing shoe, as it is normally required to do a pressure test by drilling out the shoe into a new formation, then applying a pressure gradient above hydrostatic pressure to the wellbore.

This procedure evaluates the well's ability to withstand high pressures without breaking down the formation or the cement around the casing and is the basis for establishing the depth to which the well can be drilled without setting another casing string. Clearly, if there is not competent formation around the shoe, the wellbore will not be able to withstand a high pressure gradient and the ability to advance the well to the desired depth/temperature will be compromised. If the minimum casing depth is reached and there is no competent formation, it is often desirable or necessary to continue drilling until a better formation is found (Finger et al., 1999).

3.5 DIMENSIONS SLIM HOLE WITH ROTARY DRILLING IN JABABEKA INDONESIA

For the design of the slimhole wells for the Jababeka case, a design tool has been developed, which can be download at:

ADRES: <https://www.geocap.nl>

With the tool a preliminary well design has been made for the situation in Jababeka. The design has been made by taken into account the slim hole aspects. The well design is presented in figure 11. The well design is based, as much as possible, on the geology at the Jababeka situation. However it should be noted that the available information of the geology was very limited. The used information has been taken from Geocap report WP 3.01. For the well design the Talang Akar aquifer is selected for producing and re-injecting the geothermal water. The available information about the depth and temperature of the aquifer is described in chapter 2.

Based on the limited available geologic information it is assumed that the configuration as given in figure 11 is needed. This is an assumption. It's possible that, based on information of previously drilled wells and occurred drilling problems, another casing string should be considered.

A slotted or perforated liner will be placed in the productive aquifer of Talang Akar between 2500 – 2600 meter depth. A screen with an outside diameter of 4 1/2 inch (114,3 mm) will be installed in a borehole of 5 7/8 inch (149,2 mm). The maximum allowable flow velocity in the screen has been limited at 3 m/s, to minimize the flow distribution over the screen, to reduce

pressure loss and prevent sand delivery and erosion-corrosion. The screen has got the most narrow inner diameter and therefore the highest flow velocity.

The production casing with an OD of 4.5 inch is provided with a liner hanger to make it possible to use the surface casing for housing the ESP. The surface casing has got an OD of 8 5/8 inch (219,1 mm). The production casing has the greatest length of all applied casings in combination with a small diameter and has therefore the highest pressure loss. We have chosen in the design for keeping the electric consumption low, therefore the pressure losses must be kept reasonably low. This is the reason to use a bigger pipe diameter (6 5/8") compared to other slim hole designs where the used diameter is often between 4 and 5 1/2 inch.

The ESP must be able to deliver 80 m³/h. For the selection of an ESP the information of Canadian Advanced ESP is used: <http://www.cai-esp.com/products/electric-submersible-pumps/>. An ESP which has the best efficiency point at 1200 m³/day or 80 m³/h has got an outside diameter of 6.75 inch (171,5 mm). This ESP fits in the surface casing with an inner diameter of 8.63" (219,1 mm)

Preliminary well design, slimhole Jakarta										Check strength pipes			Weight of casings
Nr	Section	Depth	Hole		OD	ID	Pipe Nominal weight	Grade	Wall thickness	Calculated burst	Calculated collapse	Calculated tension	
		[m]	[in] [mm]		[in] [mm]	[in] [mm]	[lbf] [kgm]	[-]	[in] [mm]	[Mpa] with SF	[Mpa] with SF	[1000daN] with SF	[kg]
										limit pipe spec check	limit pipe spec check	limit pipe spec check	
1	Conductor	30	14 355,6		OD 11,75 298,4	10,8 275,5	51,0 7,1	K55	0,5 11,4				212
	Tubing ESP				6,750 171,5	6,1 154,9			0,3 8,255				
	ESP	500			6,750 171,5								
2	Surface casing Section 1	800	11 279,4		OD 8,63 219,1	8,0 203,5	28,0 3,9	K55	0,3 7,8	10,4 11,5 23,4 OK	5,6 6,2 13,0 OK	16,5 26,4 194 OK	3097
3	Production casing Section 2	2500	6,5 165,1		OD 4,5 114,3	3,9 99,5	20,0 2,77	K55	0,3 7,4	29,7 32,6 42 OK	17,5 19,3 24 OK	36,9 59,0 204 OK	4701
4	Production liner Screen	2600	4,75 120,7		OD 3,5 88,9	3,1 78			0,21 5,45				weight of drill pipes 78000

Figure 11: Well design Jababeka situation

The presented well design is applicable to the Jababeka situation, where the productive aquifer of Talang Akar is situated at a approximate depth between 2500 – 2600 meter. In the Karawang area, the Talang Akar aquifer is 100 meter deeper situated.

3.6 BURST, COLLAPSE AND TENSION

The production casing and intermediate casing has been checked for burst, collapse and tension. The calculated pressure and tension, with accordance of a safety factor are below the maximum specifications of the selected casings within the geological parameters assumed for this case.

3.7 DRILLING

The presented well has been made as small as possible. However because of the use of the ESP the surface casing is relative big. This casing can only be made smaller when a deepshaft pump or vertical turbine pump is used, these pumps however are less commonly used and are therefore not investigated in more detail for this research.

The total needed hook load for this well is calculated for 86 tonnes, including safety factor (in case materials get stuck, a drilling rig of 100 tonnes must be selected. This is still a relative small drilling rig, as shown in figure 5 in Appendix 1.

3.8 DRILLING PROBLEMS AND RISKS

The most common problem during drilling geothermal wells is wellbore instability, which will lead to drilling pipe which will get stuck. Because of the smaller hole size, compared to conventional geothermal wells, the risk on stuck pipes is higher. Gas that will flow from the reservoir into a smaller casing will be detected on surface more quickly. To prevent gas kicks asensitive kick detection system is required. The system must be able to detect a small kick volume and must detect gas influxes early and shut in rapidly. Because the limited available information of the geology at Jababeka, we did not investigated the risk on gas kicks in more detail and assumed that the given standard configuration of the well should do.

4 COST ESTIMATION REALIZATION AND EXPLOITATION

4.1 ESTIMATED COSTS OF REALIZATION THE SLIMHOLE WELL

De realisation costs of slimhole wells can be divided into a couple of main items. These items and their percentage of the total costs are presented below:

- Rig operating 25 – 30%
- Casings 14 – 17%
- Cementing 10%
- Installation of the casings 9%
- Fuel 8%
- Removing (the drillstrings) out of the hole (POOH) 6%
- Bits 5%
- Miscellaneous 8 – 10 %

The rig operation is the most expensive item in the list. Most costs can be saved on the selection and deployment of the rig. For cost optimization the smallest rig as possible must be selected to perform the drilling and installation of the casings. The presence and use of the rig must be limited as much as possible.

The time needed for mobilisation, drilling, running and cementing the casings, measurements, development, production tests and completion has been estimated. The total needed time to realize one well is approxematly 40 days.

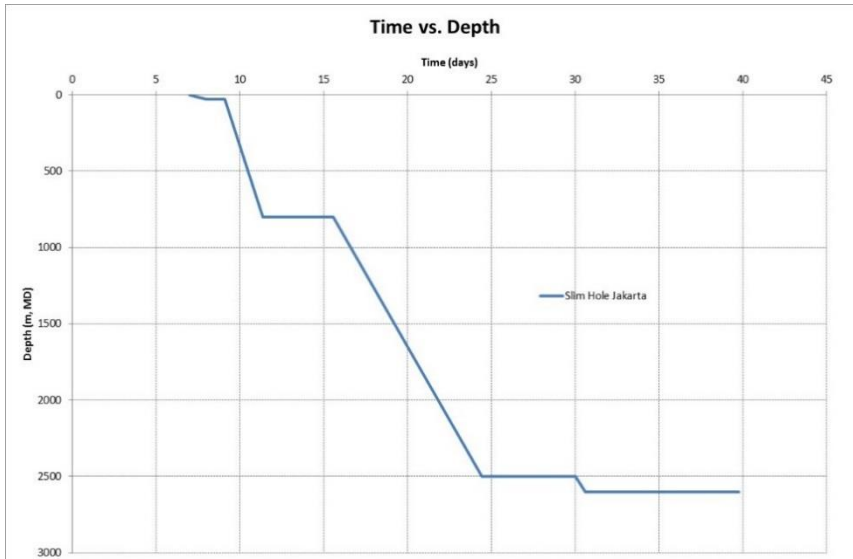


Figure 12: Indication of drilling time versus the drilling depth

The estimated costs for realisation of the well as presented in figure 11 are between \$ 1.900.000,- and \$ 2.200.000,- per well. The realisation costs per meter are between \$ 730,- and \$ 846,-. The indication of the drilling time versus the depth has been presented in figure 12.

4.2 EXPLOITATION COSTS

The costs for exploitation are determined by several factors:

- Energy consumption during use
- Maintenance
- Management
- Replacement/revision of parts

The energy consumption of the geothermal system is calculated in detail. The other factors are based on an average percentage of the realization costs.

4.3 ENERGY CONSUMPTION DURING USE

Occurring pressure losses during use at maximum capacity

For using the thermal energy the groundwater must be pumped up from the formation, must flow through the pipework and heat exchanger(s), must be filtered and must be pumped back into the formation. During this process pressure losses will occur caused by resistance.

It is important to know the total amount of needed pressure to calculate the pump energy. The pressure losses for the producer and injector are calculated separately. The pressure losses are based on the pipe diameters, lengths and maximum water flow of 80 m³/h. All calculated pressure losses are presented in table 2

Table 2: calculated pressure losses at a flow rate of 80 m³/h, during use of the wells

Producer	Pressure loss	Injector	Pressure loss
	[bar]		[bar]
Screen	1.7	Screen	1.7
Production casing	16.2	Production casing	16.2
Surface casing	0.07	Surface casing	0.2
Reservoir	6.6	Reservoir	10.7
		dp natural injection pressure	-8.9
		Pipework, HEX, filterunits	4.0
Total	25	Total	24

Next to pressure losses in the producer and injector, the pressure losses in the system are assumed to be 4,0 bar. The total electric power for the ESP and booster pump is calculated at 167,5 kWe.

5 FEASIBILITY

5.1 CASE JABABEKA INDUSTRIAL ESTATE

In workpackage 3, a feasibility has been carried out for the Jababeka Industrial Estate. To match the geothermal heat capacity, multiple users need to be connected. In this case, the feasibility of a slim hole for a single user is studied.

Heat Demand

At Jababeka, the following potential heat demand is identified:

Table 3: Potential heat demand at Jababeka

Customer	Type	Temperature
		[°C]
Unilever	Food and consumer goods	100
L'Oreal	Consumer goods	70
Fajar Paper	Pulp and paper	110
Fajar Paper	Pulp and paper	160

Based on temperature, L'Oreal is selected as the most interesting potential heat demand. The capacity of the heat demand of L'Oreal is estimated at 10 MW.

Energy concept

The energy concept is shown schematically in figure 13. Hot brine is extracted out of the production well. The temperature of the brine is expected to be 135°C (see chapter 2). In a heat exchanger, heat is transferred to the heating grid. The brine will cool down and is injected in the injection well at a temperature of approximately 85°C. The thermal capacity of the slim hole is estimated at 4,4 MW at 80 m³/h. An electric submersible pump (ESP) is necessary to inject the brine.

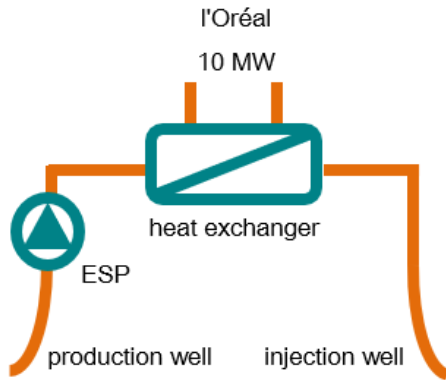


Figure 13: Schematic overview energy concept

Sustainability analysis

The primary energy consumption is calculated. This energy consumption is compared to a conventional concept, in which case hot water is produced with gas fired boilers. A summary is given in Figure 14.

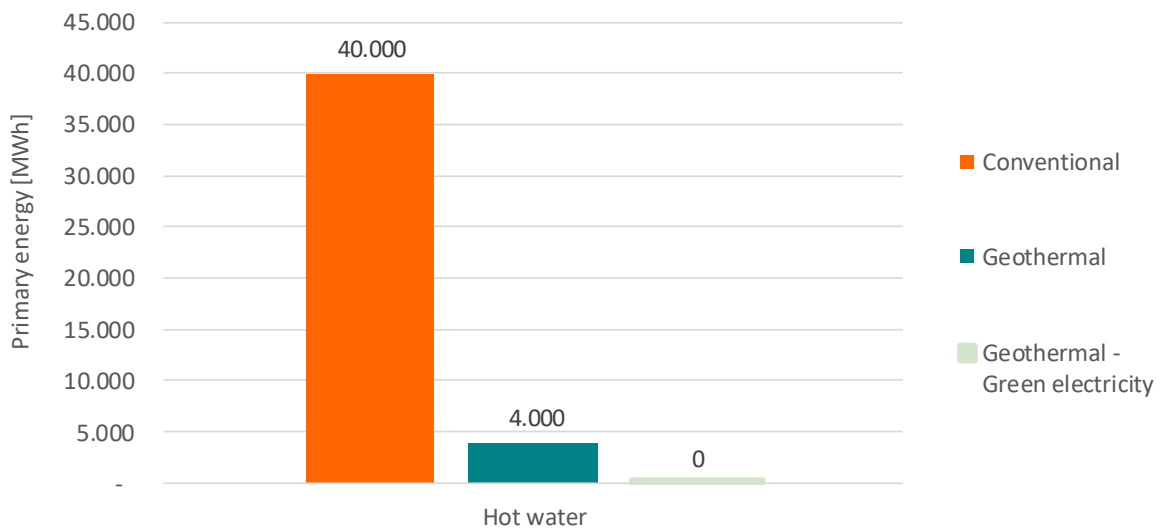


Figure 14: Primary energy consumption per year

The geothermal concept requires considerable less primary energy than the conventional situation (90%). The primary energy reduction can be decreased further by using green electricity.

Using the primary energy consumption as shown in Figure 14, the CO₂ emissions are calculated. The results are shown Figure 15.

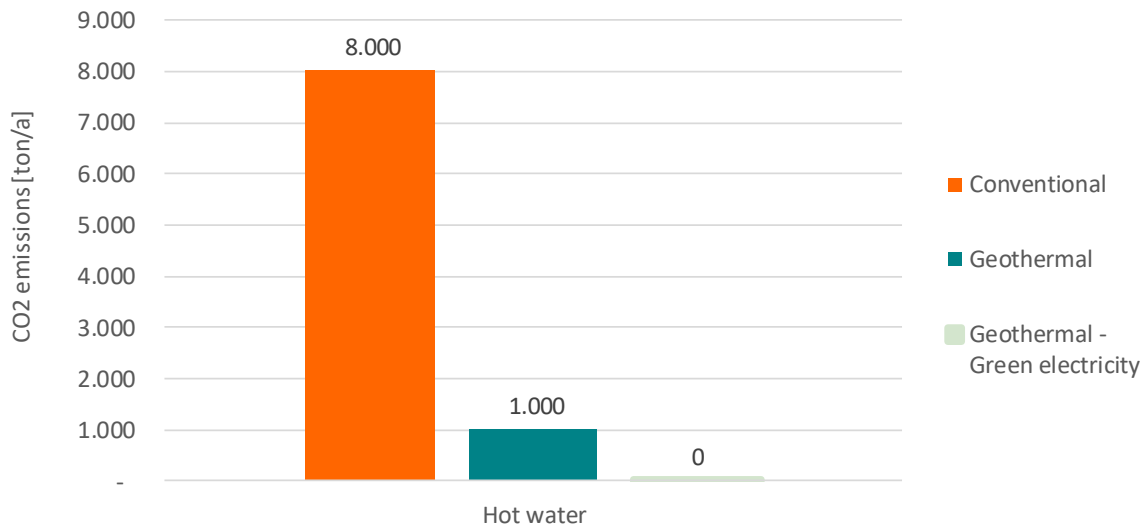


Figure 15: CO2 emissions per year

The CO2 reduction is significant (88%).

5.2 FINANCIAL ANALYSIS

The financial analyses is set up for for one slim hole.

The investment costs, exploitation cost and revenues have been estimated on a quick scan level. The drilling costs have already been presented in chapter 3. To estimate the remaining costs and revenues, general indicators are used. Values used can be found in Appendix 1. Also, the Payback Period (PP) is calculated, using the estimated cost and revenues. The results are shown in Table 4. Also, the results of workpackage 3 are shown. In work package 3, multiple users were connected by a heating grid to a standard geothermal well with a capacity of 25 MW.

Table 4 Estimated costs and revenues with slim hole and standard well configuration

CAPEX		Hot water l'Oreal	Multiple users
		Slim hole	Standard well
Wells	\$	4,000,000	16,900,000
Geothermal installation	\$	1,200,000	2,000,000
Insurances	\$	500,000	1,700,000
Design & Consultancy	\$	600,000	2,600,000
TOTAL	\$	6,300,000	28,500,000
OPEX			
Electricity	\$/year	100,000	1,300,000
Maintenance & operation	\$/year	150,000	600,000
TOTAL		250,000	1,900,000
REVENUES			
Heat	\$/year	1,060,000	6,000,000
BUSINESS CASE			
INCOME	\$/year	800,000	4,100,000
PP	\$/year	8	7

Concluding remarks

A slim hole is an interesting option to supply single industrial users with sustainable heat. The payback period is well within the technical lifetime of the well (30 years). Although the payback period is higher than a large scale solution, the required investments are much lower, risks are smaller and required space is limited. Also, only one launching customer is required. Despite the higher PP these aspects improve the overall feasibility significantly. A slim hole project could be used as a demonstration project and for exploration purposes. Once a slim hole well is successful, it will become easier to convince other industrial users and to scale up.

6 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSIONS

- Slim holes can supply industrial users with sustainable heat.
- In case of hot water production for single industrial users, a payback period is estimated at 8 years. The investment required is estimated at 6 M\$.
- Compared to standard (large scale) geothermal wells, small projects using slim holes will be much easier to realize, due to
 - much lower investments
 - small projects are easier to organize (only one user/heat-consumer required)
 - Due to a better match with the local demands, it fits for purpose and therefore it can be used more widely
 - The impact of several risks are limited
 - Space requirements are limited

6.2 RECOMMENDATIONS

Indonesia has large geothermal potential. This potential can be used for direct heating purposes for efficient and sustainable heating purposes in industry. Due to the limited size, slim holes can be used for a large range of industrial single users, making stakeholder management much easier compared to standard (large) geothermal projects. Once realized, a first project can set an example for more slim hole projects, or for a more large scale projects where multiple users combine their efforts. To initiate this opportunity, the following steps are suggested:

- Find a launching customer. Focus on the industrial estates within a sedimentary basin, such as Jababeka industrial Estate or Karawang International Industrial City.
- Determine, together with the industrial client, possible integration concepts.
- Update the analyses, using one or multiple integration options.
- In case of a positive business case, many more steps will be required. These next steps can be worked in more detail once a customer is involved, but will at least consist of getting required permits, environmental impact analyses, perform a more detailed geological study, update integration options and business case and organizing financing. Also, additional exploration may be required.

In the major cities a lot of big buildings (offices, hospitals, etc.) are present. All these buildings have a cooling demand. With absorption cooling, thermal heat can be converted in cooling energy. This method is a proven technology as a sustainable alternative for building air conditioning systems. The energy demand (cooling) is estimated between 1 – 2 MW thermal energy. The required temperatures vary between 100 – 150 °C. Therefore absorption cooling could be an interesting case to work out in future for the slimhole drilling concept in sedimentary basins.

Using techniques like binary cycles temperatures of >90 °C can be interesting to make electricity. The slimhole drilling concept in sedimentary basins could be feasible. IF Technology worked out the feasibility of small scale facilities (mini geo) and concluded that this could become feasible in less developed area's without electricity infrastructure and where oil & gas is scarce and expensive (ref. 10, Quickscan MiniGeo - offgrid electricity and heat for remote communities, 14-3-2016).

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APPENDIX 1

What is a slim hole

There are various definitions which are used for the term slim hole. They all share the same principle and that is the reduction of drilling costs by reducing casing and drilling costs. The most common found definitions of slim holes are:

- A well with a final drilling diameter smaller than 6 inch;
- A reduced number of casing strings (no possibility to apply a smaller casing string when drilling problems occur), this leads to smaller drilling and casings diameters.
- Small diameter boreholes drilled at the end of conventional wells;
- A well in which 90% or more of the length with an open hole diameter of 7" or less;
- Diamond wire line-cored holes.

Slim hole drilling can be used both for exploration drilling as for the drilling of production wells.

History of slim holes

The concept of slim hole drilling has been developed to reduce the time and cost of exploration for oil and gas. The urgency to cut costs is strongly related to the oil price and therefore the use of slim holes varies over the years. The investigation into the possibilities of smaller wells started in the early 1920s. In the 1950s several slim hole wells for production were drilled by Carter oil in several states of the USA. The savings were between 3% to 25% recorded in 108 wells, which were drilled in 1957. The Stekoll Petroleum company drilled over 1000 slim hole wells between 1944 and 1959. These wells were completed with a 2.875 inch casing and had a cost saving of 17%.

By 1961 slim hole drilling was applied at a relative large scale in several parts of the world, 131 companies had drilled a total of 3216 slim hole wells with a final diameter of 171,5 mm (6.75") or smaller. The depth varied between 950 – 2000 meter. Despite the many drilled slim hole wells the interest in slim hole drilling diminished in the 1960's. This was caused by operational problems, mainly with the drill bit, weak drill pipes and mud system. A big disadvantage was the decreasing penetration rate of the thinner sections of the wellbore (<7.875").

In 1970 a 3535 meter deep slim hole well with a final diameter of 3.5" (89 mm) was drilled in Canada. The costs of the realization were half the costs of a conventional well drilled in the surroundings. A Swedish exploration Group drilled in Sweden between 1977 and 1981 in total 93 slim holes with approximately a 2.5" (63 mm) final borehole, with a saving of 75% compared to conventional drilling methods.



Figure 1
Cardwell Manufacturing Company of Wichita, KS. How to cut costs with Slim Hole Drilling, 1955.

The slim hole drilling techniques have been improved recently due to reducing budget for exploration and production wells. Budgets become smaller due to the recent reduction of the oil price. Slim hole drilling is now seen as a comprehensive alternative for both exploration drilling as drillings for production wells.

Slim holes in Indonesia and south east asia

The following (known) slim hole drillings in Indonesia (and Phillipines) are recorded and used (in most cases) for exploration:

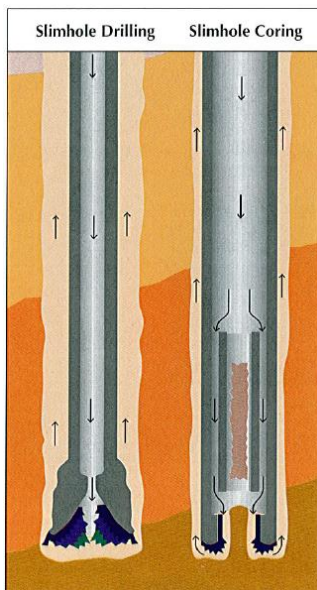
- 1964 Sumatra: Pan America Indonesia drilled 4 slim hole wells, remote swampy area
- 1985 Irian Jaya: Conoco and Westburne Drilling Co, drilled 12 slim hole wells, remote area
- 1970 – 1994 Darajat: Several production wells and exploration wells has been made
- 1993 Wayang Windu, exploration slim holes by Pertamina
- 1996 Wayang Windu, another 4 wells were rotary drilled at the top, the lower part was continued cored to a depth of 1500 m.
- 2014 Montelago in Mindoro, Phillipines, cored to a depth of 1250 m.

To our knowledge there hasn't been a case in Indonesia where a slim-hole well is used as a production well.

Drilling methods

Most common used drilling techniques which are applied for drilling slim holes are, diamond wire line-cored drillings and (scaled down oilfield hardware or retrofit) rotary drillings (see figure 2). Recently also the Coiled Tubing drilling has been developed for slim hole drilling.

In the following paragraphs the different methods are described.



*Figure 2
rotary drilling compared to
continues coring (Source: Oilfield
review)*

Diamond wireline continuous coring

Coring rigs are used for the past 60 years for exploration, for example to explore ore bodies in the mineral industry. The drilling is done with diamond bits which cut a cylindrical kerf in the rock. The cuttings which are produced by the diamond bits are very fine and are washed out with injected water and can be transported to the surface through the annulus. In the hollow center of the drill string, the inner barrel, the core is collected. When the length of the inner barrel has been filled, rotation of the drill bit will be stopped, and the drill string must be raised. With this action the core will break just behind the bit and gets stuck in the inner barrel. A wire line is used to retrieve the core sample from the inner barrel quickly to the surface, which results in a near-perfect core sample of the underground. With this method it is not necessary to remove the drill strings to get the core samples to the surface.

A great benefit of core drilling is the ability to drill easily through lost circulation zones. When drilling with the rotary technique these zones are difficult to drill through. Because of the lack of returning of the cuttings no information of the underground is obtained and more dangerous, overpressure can be lost.

Figure 3

Example of core samples (ISOR, Montelago)



Specific characteristics of the continues coring rigs (or combined rigs) are:

- Small rig dimensions, self erecting mast (see figure 4 for an example);
- Small workspace footprint < 3.000 m²;
- Small crew: 2 or 3 men;
- Maximum drilling depth 2500 meter (with a 20 ton rig);
- Drilling diameter final depth (different size possible, see below), most common: NQ 76 mm / 3 inch;
- Hook load: 20 - 50 ton;
- Road able (truck or trailer mounted).

Diamond wire line coring works with standard bit sizes, an overview is presented in table 1.

An example of a diamond core continues core drilling rig is presented in figure 4.

Table 1: Standard "Q" continues wire line core drilling bit sizes (Source: Wikipedia)

Size	Hole (outside) diameter, mm		Core (inside) diameter, mm	
	[mm]	[inch]	[mm]	[inch]
AQ	48	1.9	27	1.1
BQ	60	2.4	36,5	1.4
NQ	75,7	3.0	47,6	1.9
HQ	96	3.8	63,5	2.5
PQ	122,6	4.8	85	3.3

Benefits diamond wire line coring

- Good (undisturbed) soil samples;
- Small rig, small crew and easy transport, mob/demob
- Drilling through lost circulation zones without problems on stability or no loss of samples.
- The geology and permeability can be examined more in detail.

Disadvantages diamond wire line coring

- Only small drilling diameter possible (max. PQ: 122,6 mm / 4.8 inch);
- Low drilling speed. The drilling time is almost twice compared to conventional (rotary) drillings. The drilling time for a 1500 meter borehole takes 60 – 65 days;
- Limited drilling depth;
- Cannot be used in sedimentary basins / unconsolidated formations;
- Possibilities for Wire line logging is limited caused by the smaller drilling diameter;
- Drill strings are weaker because of the smaller diameters.

Rotary drilling

The rotary drilling technique is the most common method for exploration drilling and for production wells for gas, oil and geothermal systems. The principle is that the drill bits cuts the formation and the cuttings will be transported from the borehole by the drilling fluid. The drilling fluid is pumped into the drill string and is released at the drill bit. The fluid and cuttings will flow through the annulus upwards to the surface. The cuttings will be separated from the fluid, which is pumped back to the drill string.

For the oil, gas and especially geothermal industry, in general, wells are provided with relative large casing diameters. This results in relative large rigs and require a work area between 4.500 - 18.000 m². These rigs are expensive and big to transport. Downscaled rigs or especially designed rigs for slim hole drilling are available and often called “compact Drill” rigs.



Figure 4
Core drilling rig

Specific characteristics of the required compact drills are:

- Smaller rig dimensions, (self-erecting) and shorter mast compared with large rig;
- Small workspace footprint < 4500 m²;
- Requires a small crew (3-4 men);
- Can be transported with minimum amount of truck loads 20 trucks or less;
- Road able (truck or trailer mounted) or helicopter transportable;
- Hook load 50 – 150 ton;
- Drilling depth maximum 2500 meter (with a 100 ton rig);
- Minimum drilling diameter to final depth: smallest standard roller bit: 95,3 mm (3.75 inch);
- Maximum drilling depth: 2500 meter, with drilling diameter 127 mm (5 inch) with 100 ton rig (see figure 6).

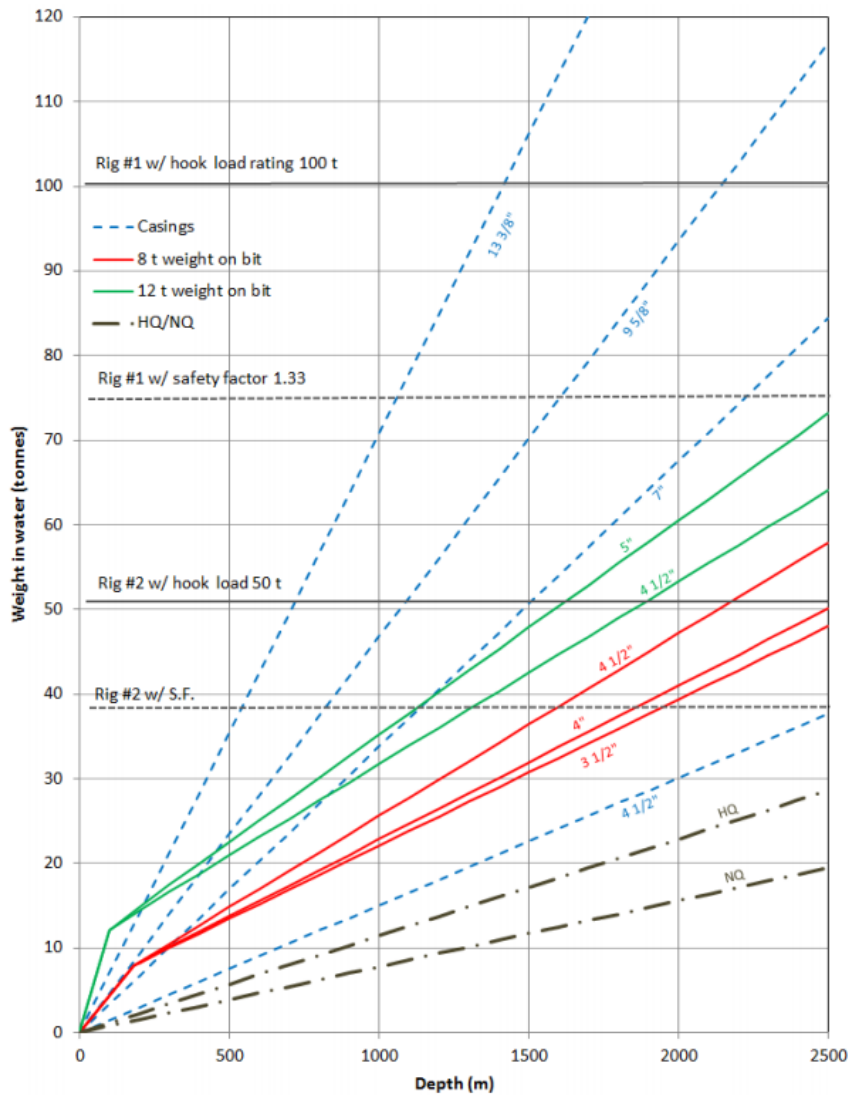


Figure 5
Rotary rig (100 t) drilling slim hole to 1500 m (Source: ISOR)

In figure 6 a graph is presented which shows the possibilities in depth for different drilling diameters and casings.

Figure 6

The diagram shows the weight of different size drill strings and casings in water vs depth. NQ and HQ are coring rods (Source: ISOR)



Benefits rotary drilling

- Wide range of drilling diameters are possible;
- Relative high drilling speed;
- High drilling depths;
- Commonly used technology, so high availability of equipment, knowledge and trained people
- Can be used in sedimentary / unconsolidated formations;

Disadvantages rotary drilling

- Big footprint, bigger impact on environment (compared with diamond coring);
- Change on drilling problems in lost circulation zones.

Coiled tubing drilling (CTD)

Coiled tubing drilling, have the potential and a lot of benefits for drilling effective slim hole wells. A coiled tubing unit is in most cases smaller than a standard rotary drilling rig and relative easy to mobilize. Because no drill strings are used, installation and de-installation of the drill bit takes less time compared to rotary drillings (see figure 7 for an example of the principle). All these items results in lower costs. Despite of the benefits the borehole diameter is very limited (most cases 95 mm / 3.75 inch drill bit), making it impossible to drill the top of the hole. It is also impossible to install the casings with the coiled tubing unit. Therefore a rotary rig must drill the top of the hole and must install the surface casing. Coiled tubing drilling is often applied at existing production wells for making sidetracks.

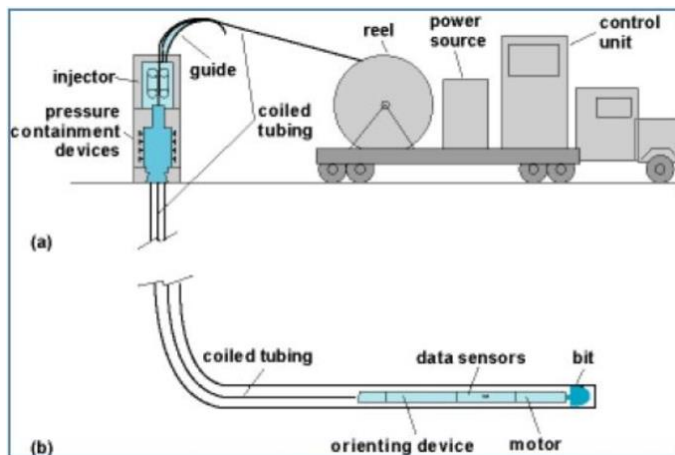


Figure 7
Schematic of coiled tubing drilling
(source: www.interfaceforce.com)

Combination/hybrid rigs

There are hybrid rigs on the market who have the ability to do both rotary and core drilling with the same rig. However these rigs are more related to core drilling rigs as to rotary rigs. These rigs can use the rotary technique to drill through relative soft overburden on top of the consolidated formation or rock. As soon as this consolidated formation is hit, the rig can change from rotary to core drilling. Examples of hybrid rigs are the Sandvik UDR1500 rig (UDR stands for: Universal Drill Rig) or Boart Longyear LX16 (see figure 8 for an example).

Both rigs have a hook load between 18 – 22 tonnes.

Figure 8

*Example of a hybrid rig
(Boart Longyear LX16)*



Benefits of slim hole drilling

- The most important benefit are the cost reduction of the exploration or development wells. The cost savings vary between the purposes. For exploration drillings cost savings between 40% to 60% in remote areas are recorded (Source: A review of slim hole drilling). The cost savings are achieved by saving on: smaller drilling rigs, reduced casing sizes, less site preparation, easier mobilization of equipment, reduction of consumables (bits, mud, cement, fuel), less cuttings to dispose and need fewer crew to operate.

Disadvantage of slim hole drilling

- Limited yield of geothermal production
- The use of wire lines and logging tools is limited, because of the outside diameter of the tools (between 2.25” – 8.5”) and smaller drilling diameter.
- A more sensitive Kick detection system is required, because if gas kicks occur in slim holes, these kicks will show up very quickly on surface.
- In the past drilling slim holes caused more down hole problems, due to improvement equipment and operational practices failures have been decreased.

Defining preconditions for a well design

For the remainder of this study, we have to establish the principles for the implementation of slim hole wells.

Based on the information gathered from the literature review, the following conditions are defined and supported:

- A slim hole well has a final drilling diameter of 6” or less to apply the smallest casings as possible. By doing this there is no possibility to apply a smaller casing string when drilling problems occur.
- The aim of this study concerns sedimentary basins, with an average depth between 1500 and 2500 meter below ground level. These conditions determine the drilling technique. Geothermal production wells in sedimentary basins can be drilled best with the rotary technique. Diamond continues core drilling is not intended for sedimentary basins and can therefore encounter more drilling problems.
- The production well should be able to be provided with a submersible pump, the premise is that the well is not self-flowing. This results in a relative high upper casing diameter in order to make space for the submersible pump. Due to the application of an submersible pump, diamond continues core wire line drilling is in most cases not possible due to the limited maximum drilling diameter (95,3 mm).
- This results for this investigation in the use of a small rotary rig. The maximum hook load is set at 100 tonnes. This hook load makes it possible to perform drillings with a maximum depth between 2500 – 2800 meter below ground.