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# EXTENDED REACH AND HIGH INCLINATION DRILLING GEOTHERMAL WELL IN WAYANG WINDU

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## ABSTRACT

On 2011, Star Energy Geothermal Wayang Windu, Ltd (SEGWW) embarks into drilling geothermal wells in the Wayang Windu area purposely to enhance its steam supply and explore additional field for further evaluation and development.

The drilling continuous without any major difficulties encountered. After drilling four wells with an average depth of 1,800 meters, SEGWW subsurface team proposed to delineate to areas where a high angle drilling is necessary to reach possible faults that may enhance steam supply. The design of this well with a long reach drilling target, calls for a $67^0$ angle and slightly build to reach the final fault. The well is intended to confirm additional reserves and gather additional data that is necessary in confirming the field steam supply situation. This created a situation where drilling team members were uncomfortable as this is the first high angle well in Wayang Windu and possible all other geothermal fields in Indonesia and probably in Asia. The lack of offset data made it uncertain to accomplish this ambitious plan of a long reach drilling in geothermal wells. One critical factor that is very challenging is the risk of drilling extended reach and high angle under loss circulation zone. Other high potential risks during drilling that were identified are: very tight window of target, loss circulation during steering, insufficient hole cleaning, insufficient casing weight to land it on bottom, no directional control during drilling the last hole section and unknown formation behavior.

This paper presents a success story of the SEGWW drilling team on this extended reach and high angle well. It was completed to a final hole inclination of $80^0$ at 2,450 meters. The team composed of highly motivated and dedicated personnel and fully supported by Star Energy management made this “NEVER BEEN DONE” before drilling program a success. The well was completed with a minimum none productive time as well as below budget and on target. The success outcomes make the level of confidence for SEGWW drilling team to drill high angle in Wayang Windu.

## INTRODUCTION

Limitations to reaching new geological targets are not easily achieved, especially for long reach and high inclination wells in the loss zone formations. The challenge to drill long reach depth and higher inclination well began when the subsurface team delivered the proposal to drill the MBB-6 well. MBB-6 is the fifth wells of 2011 Star Energy geothermal drilling campaign, while WWA-6 is the well after which followed the success of extended reach and high inclination drilling ever in the area.

This paper will describe stages of planning and executing the MBB-6 well and summary of the projects success include WWA-6 brief performance, which brings up the best drilling performance in Star Energy. Some additional background data will also be presented for performance comparison. The comparison is between last 2006 drilling campaign vs 2011 drilling campaign performance.

Some assumption in this paper at the planning stage are considered from the theory of drilling exploration wells. Unpredictable formations, and unknown data of formation increase drilling risk. Some technology opportunity were also applied on this well.

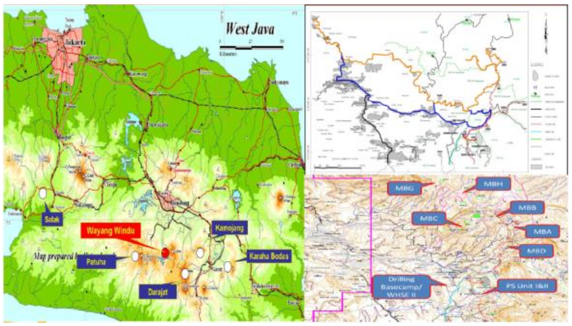


*Figure 1: Wayang Windu field location and area.*

## PROJECT PROPOSAL AND PLANNING

To drill the MBB-6 is to supply steam for Wayang Windu Phase 3 Expansion Project. The well has also been designed to specifically target major faults within the Puncak Besar Reserves to the North of MBB well pad. The information gained from this well will be used to improve confidence with Puncak Besar Reservoir and to confirm the location for the proposed new well pad. To achieve the objectives, a high angle long reach well is proposed.

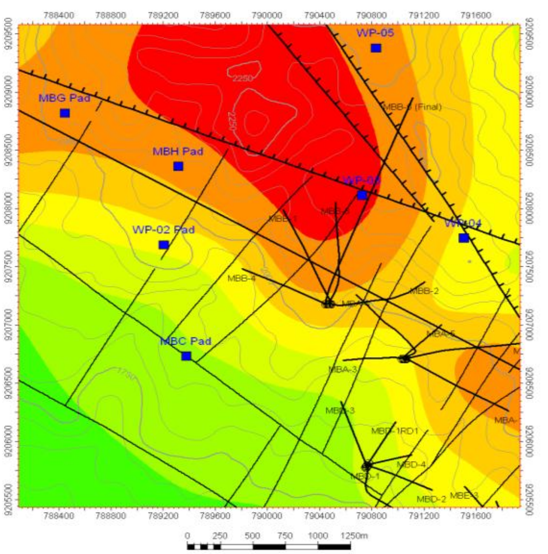


*Figure 2: MBB-6 Geological target proposal*

### Well Targeting

Intensive tripartite meetings were conducted between well targeting team (consist of reservoir and geologist), drilling team and management to view~~ed~~ the options of drilling MBB-6 wells. The options took the accounts of geological target, reservoir economic and drilling risk and tools capability and availability. This paper will only discuss and introduce the drilling working level as the topics limitation.

The drilling engineer identified the ranks of the risk, the difficulties and the mitigation plan. The output would be useful to produce the appropriate drilling program. The final MBB-6 drilling program has been adjusted to minimize the problems which would probably appear while drilling high inclination in the loss zone and deeper hole section.

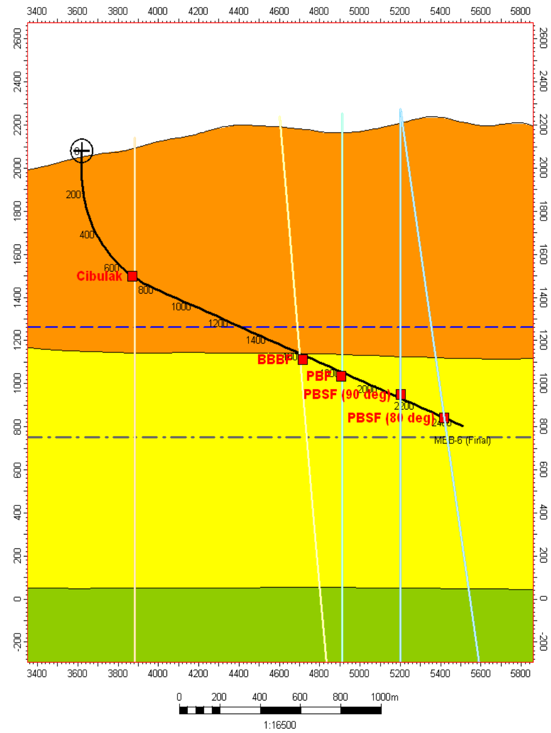


*Figure 3: MBB-6 Geological cross section plan*

### Well Plan (Directional Drilling Program)

From the begining of 2010 drilling campaign some technique of improvement were proven optimizing the operations. On this extended reach drilling (ERD) well planning stage, the drilling team is confident and consistently assessing the geological proposal and some critical situations that may jeopardize the success of the operations associated to long reach and high inclination.

The risk assessment meeting which were attended by all contractors involved in the project was conducted to identify the constraints of a successful ERD, which include downhole drill string and casing movement, applying weight to the drill bit, possible buckling of casing or drill string, and running casing successfully to the bottom of the well. Casing handling was not a problem as the rig capacity is 1,500HP cyber onshore drilling rig.

As from the geological proposal, the MBB-6 wellplan required to kick off shallower (at 100mMD/TVD) to intersect all of five geological targets. While four of the last targets present a narrow boundary between 1,260m elevation and

750m elevation (or 823mTVD and 1,333mTVD). The above conditions must also be following the standard procedure in drilling in SEGWW to limit the dogleg severity (DLS) as much as $3^0$/30m. One of the program requisites is also to end the directional work within 17.5” hole section.

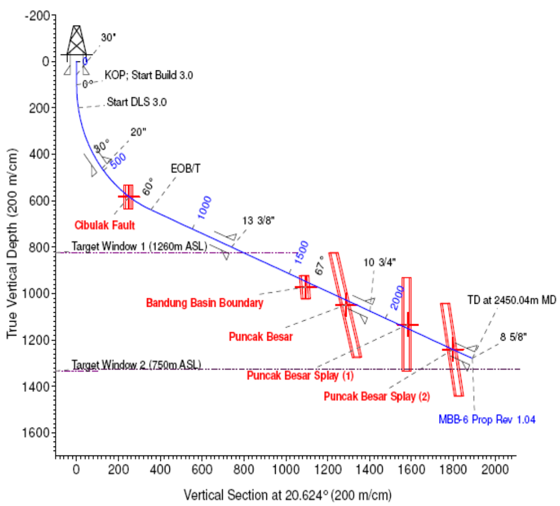


*Figure 4: MBB-6 Directional Plan (section view)*

As mentioned in the geological proposal, the target direction for this MBB-6 well is far to the north from the origin. This situation made the wellplan more complex which needs to turn the hole during kick off. The complexity is more to avoid the collission to the adjacent wells within the pad.

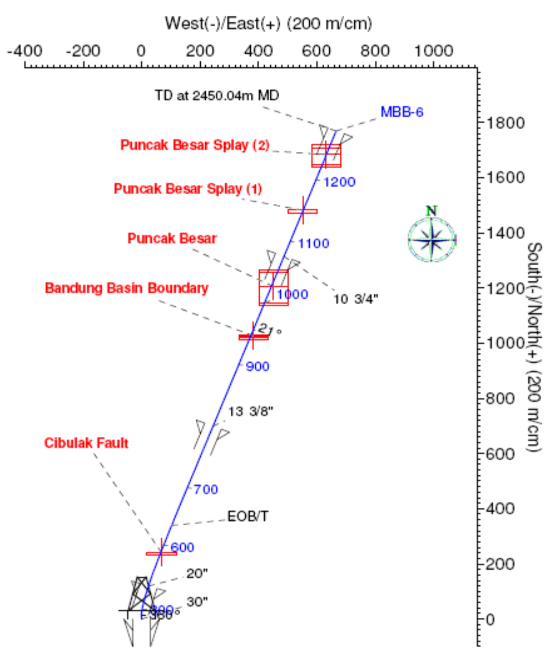


*Figure 5: MBB-6 Directional Plan (plan view)*

Kick off point (KOP) shallower in 26” hole section was reflected in the plan to avoid collision to the nearest wells. The depth of 100mMD was set as KOP to reach a target inclination at 785m MD as much as $67.4^0$. The well had to turn to the target direction beginning from the kick off point far to the north directions to $21.5^0$ azimuth then turning around heeding to $355^0$ azimuth to avoid and get away from the adjacent wells. This is the result of the anti-collision analysis.

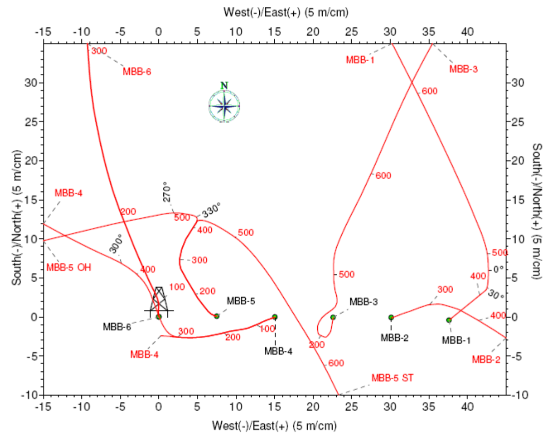


*Figure 6: MBB-6 Directional Plan (spider plot)*

***Torque and Drag***

In the theory of Extended reach drilling (ERD), torque levels are generally more dependent on wellbore length than on tangent angle. Higher angle wells tend to reduce torque levels, as more of the drillstring will be in compression. Consequently tension and contact forces around the top build section are reduced.

Figure 7 shows the results of the torque and drag analysis on 17½” and 12¼” hole section by inputting all the bottom hole assembly (BHA) component, with the assumption of $67^0$ inclination which is the highest inclination to achieve. Moderate results of friction factors made the team confident that 17-1/2” BHA will complete the directional work.

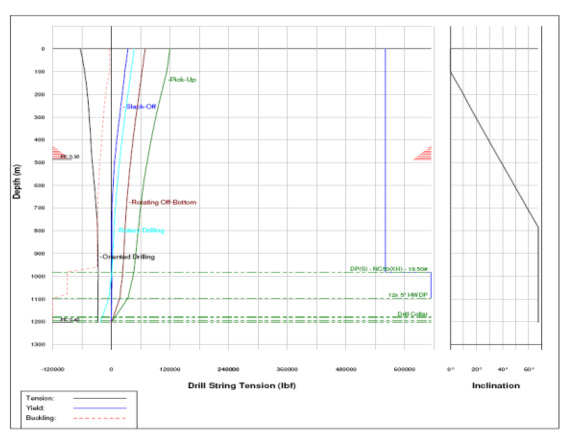


*Figure 7a: 17½” hole section Torque and Drag analysis.*

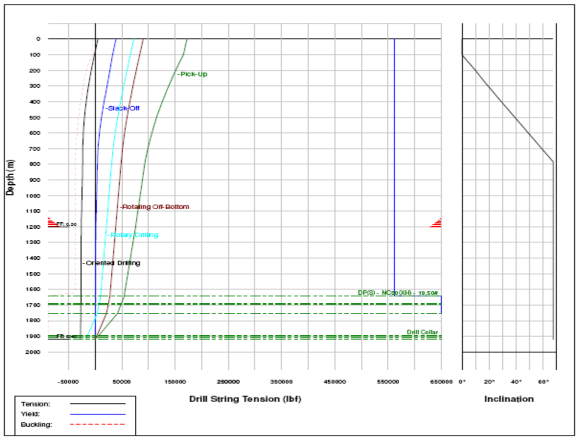


*Figure 7b: 12¼" hole section Torque and Drag analysis.*

From the torque and drag analysis the results of 12 ¼" hole section is higher than 17 ½" hole as in the deepest section the higher weight would affect the torque and drag between the pipe and the wellbore. Additional of the weighting factors, the absence of buyoancy factors will increase the torque and drag in the 12 ¼" and 9-7/8" hole section. Absence of buoyancy factors due to only using water instead of mud during drill out 12 ¼" hole and beyond.

**Hole Cleaning with Water in Inclined Hole**

The essentials of hole cleaning primary concepts in ERD projects are the three pilars, these are; sufficient flowrate (annular velocity to lift up cuttings), drillstring movement (rotation) and mud rheology itself. The other significant influences are the borehole angle, drilling rate, hole size and the flow regime (turbulent or laminar).

In geothermal drilling the greatest challenge is how to clean the hole in a highly deviated and loss circulation zone hole using water and sometimes air only. It is apparent that another action and solution has to be applied in order to attain a clean hole as we proceed to drill the hole in this situation. The technique applied is to regularly pump Hi-Vis pill to hopefully bring the cuttings up and force to the loss or fractured zone.

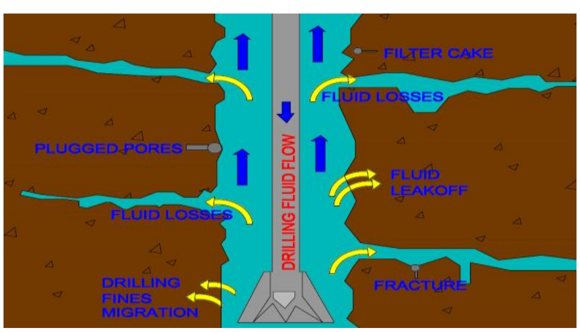


*Figure 8a: Fluid circulation in conventional system with mud.*

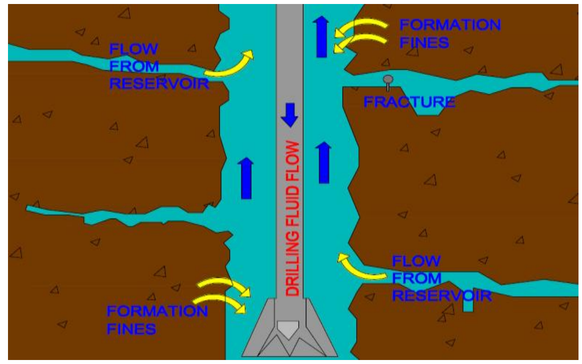


*Figure 8b: Fluid circulation system using aerated drilling.*

Evidence from previous wells in MBB pad has shown that cuttings deposited with low pump rates at upper loss zones have re-entered the well in spite of increased pump rates at deeper depths. Cuttings can re-enter the hole as a result of fluid flowing back into the well from the upper permeable zone.

The cuttings re-entry or flow back is caused by a pressure reduction in the hole, well kicks, flow between two permeable zones, swabbing while tripping in or out, or working the pipe. A number of wells found to have flow between two permeable zones was considered the cause of premature completion of drilling due to tight hole conditions.

Completion tests with no pumping into the well has shown that geothermal fluids entered the well at the upper most loss zone and flowed down to deeper permeable zones, The flow rate could not be quantified with the instrumentation used. However, problems when encountering the deeper zone indicated that this flow was significant enough to flush back cuttings deposited earlier in the upper zone.

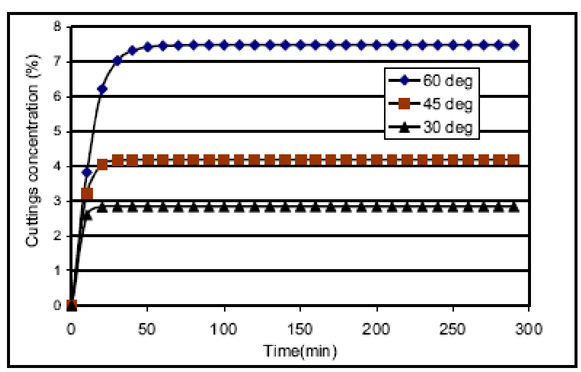


*Figure 9: Transient average cuttings concentration at different inclination.*

The best practices in cleaning the hole in geothermal operations to prevent stuck pipes that were applied are; keep the pipe moving, additional cleanup cycles, back reaming before connection, sweep hi-vis on each connection, conduct regular short wiper trips, open up all bit nozzles and control drilling rate in the loss zone.

## Casing Plan

The casing design in the previous drilling campaign was followed in this present drilling campaign except that the thread connections have been changed to premium connections due to casing integrity issues and problems discovered during well inspection of the previous wells.

| HOLE | | | | | | |
|---|---|---|---|---|---|---|
| Phase | 26" | | 17-1/2" | | 12-1/4" | |
| Depth -TVD | 1,329 | 405 | 2,641 | 805 | 4,393 | 1,339 |
| Depth - MD | 1,329 | 405 | 2,641 | 805 | 4,393 | 1,339 |
| **CASING** | | | | | | |
| Size | 20" C | | 13 3/8" C | | 10 3/4"C | |
| Top Casing at - TVD | 0 ft | | 0 ft | | 790 | |
| Top Casing at - MD | 0 ft | | 0 ft | | 769 | |
| Shoe at - TVD | 1,329 | | 2641.205 | | 4393.259 | |
| Shoe at - MD | 1328.805 | | 2641.205 | | 4393.259 | |
| Weight (ppf) | 133 | | 68 | | 40.5 | |
| Grade | K-55 | | L80 | | K-55 | |
| Coupling | GB3P | | PC | | BTC | |
| **TECHNICAL CASING DATA** | | | | | | |
| **Casing Size (inch)** | **ID (in) Type** | **Drift Diameter (Inch)** | **Wall Thickness (Inch)** | **Burst Strength (psi)** | **Collapse Strength (psi)** | **Yield Strength (Klbs)** |
| **20.000** | 18.730 | 18.542 | 0.635 | 3060 | 1500 | 2125 |
| **13.375** | 12.415 | 12.259 | 0.480 | 5020 | 2260 | 1556 |
| **10.750** | 10.050 | 9.894 | 0.350 | 3130 | 1580 | 629 |

*Figure 10: Casing for 2011 -2012 drilling campaign.*

The driver for casing setting depth is only the formation strength for that can hold the cement weight for casing shoe. While the only concern is to run the sufficient casing weight that can run to bottom in the high angle wells.

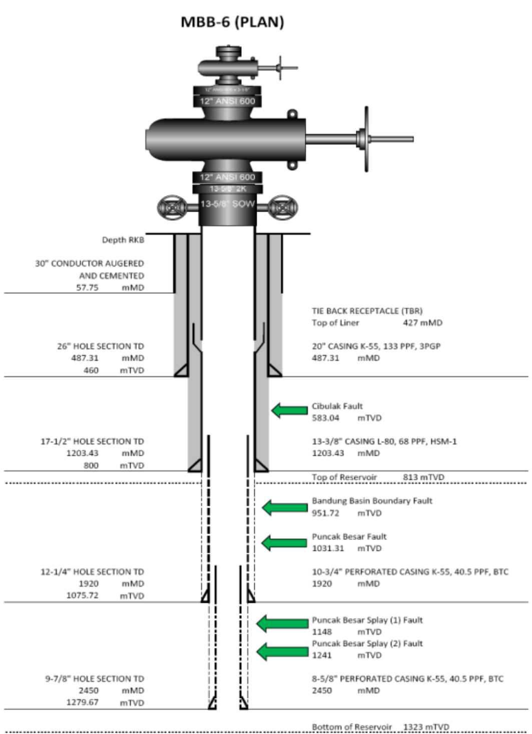


*Figure 11: MBB-6 Well Schematic (Plan).*

As shown in the well schematic, perforated liner is divided into two hole section. This strategy is more to avoid drilling long open hole at high inclination. The risk of l~~o~~osing the well is higher as cutting settling at downside of wellbore would make stuck pipe event become higher.

## Coring and Wireline Logging Plan

As required from subsurface department to gather as much as they could have the "value of information", and considering the MBB-6 is the step out well or equivalent to exploration well, formation evaluation such as coring and wireline logging is very useful for future decision making and probably define the geological mapping.

A critical part of the rapid development process is to carefully specify the functional specifications of the tool.

### *Coring Plan*

Core point is just below the 13-3/8" liner shoe for 6m length. Using the 8-1/2" coring BHA with sufficient for up to 18m of coring will be made available.

One of the results from risk assessment is to have at least 10m of 8-1/2" rathole below 13-3/8" liner shoe prior to cutting the core which accomodate coring BHA stabilization. In order to attain and recover high percentage of core, BHA stabilization was optimized by adding roller reamers in the coring assembly.

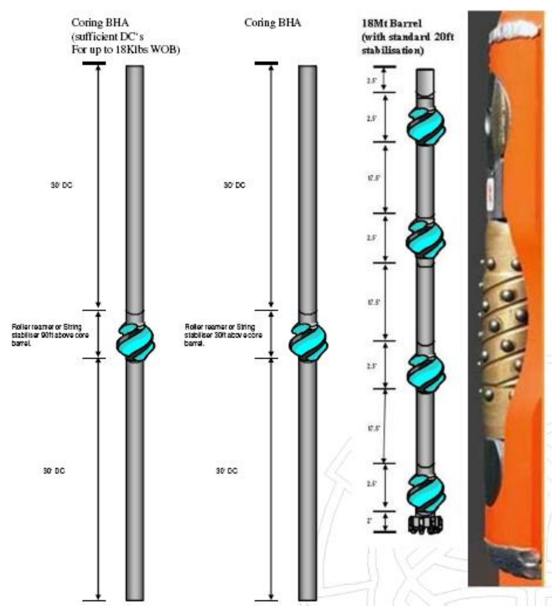


*Figure 12: Coring BHA with roller reamers.*

### *Wireline Logging Plan*

As the MBB-6 is long reach and high inclination well cathegory, and the conventional wireline logging tools would not be possible to reach open hole section above $60^0$ hole angle, the toolpusher logging

(TPL) tool was use as it is one of the viable way to convey logging tool in the zone of interest for the well above $60^0$ angle.

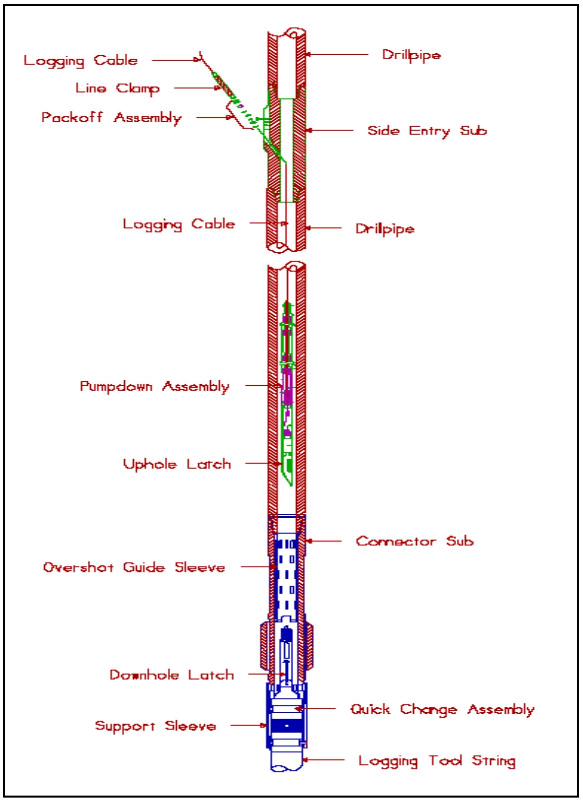


*Figure 13: TPL proposal configuration.*

Logging objective is to log the formation below the 13-3/8" shoe to TD at 2,450mMD to acquire imaging log (XRMI) and porosity (SDLT) within single trip.

## OPERATIONS PERFORMANCE

MBB-6 spudded on July 11th, 2011 at 03:30 hours and reached a total depth of 2,450mMD or 1,187.28 mTVD as per plan total depth (TD) of the well. The 8⅝" casing point was reached and the liner was ran and set on August 17th, 2011 at 17:00 hours as the last production liner.

As the technology opportunity and to fulfill subsurface requirement, the tool pusher logging TPL (GR,XRMI,SDL,BHPT) was performed in 12¼" open hole section. The TPL logged up from 1,910mMD to 1,130mMD and in 9⅞" open hole section logged up from 2,442mMD to 1,910mMD. Aside of logging, doing coring was also required which the core was cut in 9⅞" open hole section from 1,930mMD to 1,936mMD with 88.4% core sample recovery.

## Plan vs Actual

Overall, drilling the MBB-6 wells was beyond the expectation of drilling objective. Total of 48.08days to complete the well from rig skid to TD at 2,450mMD.

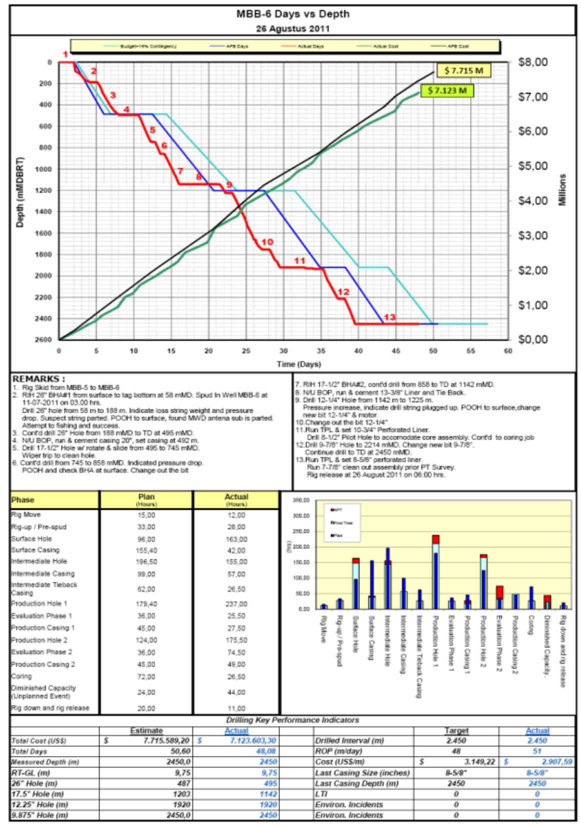


*Figure 14: MBB-6 Days vs Cost Performance.*

## Directional Drilling Performance

Nudging in the 26" hole section as shallow as 100mMD is the first challenge to drill MBB-6. Kicking off at the 26" section of the hole was successful as per plan. The angle at the shoe of the 20" casing setting depth of 495mMD was at $28.5^0$ and $22^0$ azimuth. The big 9-5/8" Mud Motor succeeded to steer up the BHA without any trouble. The only trouble from the 26" BHA was the parted 8" MWD antenna sub which was fished successfully.

The 17 ½" BHA continued to drill directionally to build up hole angle to $68.9^0$ and set the 13-3/8" liner at 1,142mMD. The target inclination and azimuth was a few meters off but considered to be acceptable as the 12 ¼" section can continue with correction back to its target.

Maintaining the hole angle and direction to hit the 1st and 2nd target is the main objective to drill the 12 ¼" hole section. Drilling the 12 ¼" hole section did not encounter any trouble, some of surface equipment failures and failure of mud motor bearing were the hinder of progress in drilling due to additional trip. In this section partial returns of drilling fluid made the team decide to sweep hi-viscous fluid every drillpipe connection as much as 50bbl to at least suspend the drilling cutting. Another preventive action to avoid getting stuck in this production hole section was to keep the pipe moving and circulating with aerated fluid most of the time. A total of 290 hours with controlled drilling was spent in this section and the 10 ¾” perforated liner was ran successfully without any difficulty.

The last section to drill was the 9-7/8” hole section to run and set the 8-5/8” pre-perforated liner. The 9-7/8” rotary hold BHA was the only option to drill 1,425m footage with total of 285 hours time spent. The directional BHA was not possible to run on this section after recognizing the 10-3/4” casing inside diameter (ID) restricted for 8-1/2” Mud Motor bent. The directional BHA that supposedly controling the hole direction and inclination was ran only to increase the drilling rate and transmitting the downhole survey and temperatures.

The drilling parameter applied in this section to maintain the inclination and direction brought up the hole inclination to $79.9^0$ of inclination and $27.8^0$ azimuth at 2,431mMD depth of survey. The clean out BHA after TPL works was successful to free the hole from obstruction.

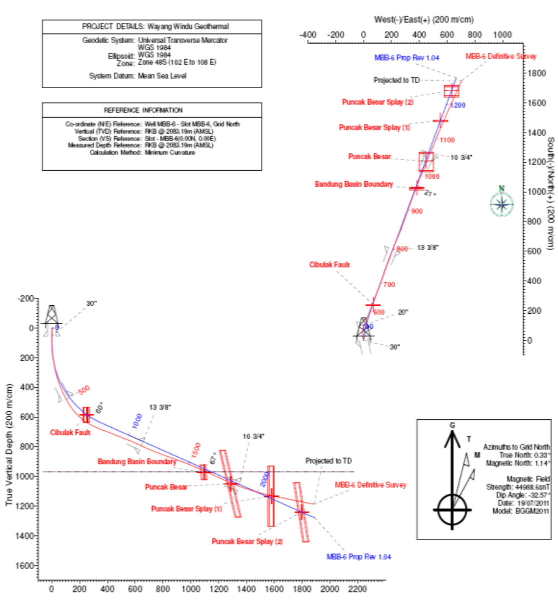


*Figure 15: MBB-6 plan vs actual directional plot.*

This leaves the wellbore at 78m on top of the last centre target (Puncak Besar Splay). However since the geologist found the actual target is Puncak Besar faults (3rd target on the plan), we can surmise that we succeeded in hitting the last target (Puncak Besar fault) only 11m on top from centre of the target and 78m on the left of centre target.

## Casing Running Performance

The very first surface casing as big as 20” outside diameter (OD) were ran in the 26” hole section without any trouble time. This is also the first record in the area for running the big casing in the directional hole. Spent 7.5 hours just to run the casing to reach bottom hole at 492mMD which leave 3m rathole for cement bond purposes.

Likewise the 13-3/8” liner reach bottom without any difficulties. The 27.5 hours spent in actual to set and cement the 13-3/8” liner and tieback was only 60% of plan time.

The 10-3/4” perforated liner was 24m off bottom as it can no longer go down due to cuttings accumulation probably due to running in at high angle section where the liner was dragging on the low side of the hole bringing with it cuttings down to bottom rathole as tag on the depth.

The combination of blank and perforated was a prefference opted by subsurface, the 10-3/4” blank pipe is to covered the lap inside 13-3/8” while the rest were perforated. Additional drill collar was attached to the running pipe after encountering obstruction at 1,620mMD which pushed the liner to bottom.

The 9-7/8” clean out BHA was ran in the hole after TPL works. The 8-5/8” perforated liner reached to the bottom of the well at 2,450mMD without any difficulty. It was programmed that an injection test will be performed after the 8 5/8” liner was ran in to the bottom of the hole, hence it was prudent on our part to clean the inside of the 8 5/8” liner to ensure that the tool will reach bottom without any possible fine cuttings obstruction. The injection test using production downhole tools was successful.

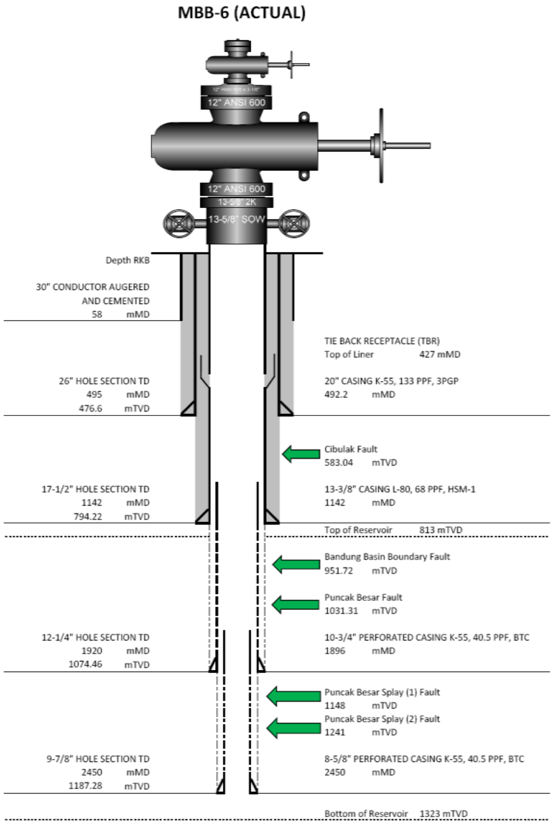


*Figure 16: MBB-6 Well Schematic (Actual).*

## PERFORMANCE COMPARISON

As shown on Fig.17 that MBB-6 well is the deepest wells in Wayang Windu.

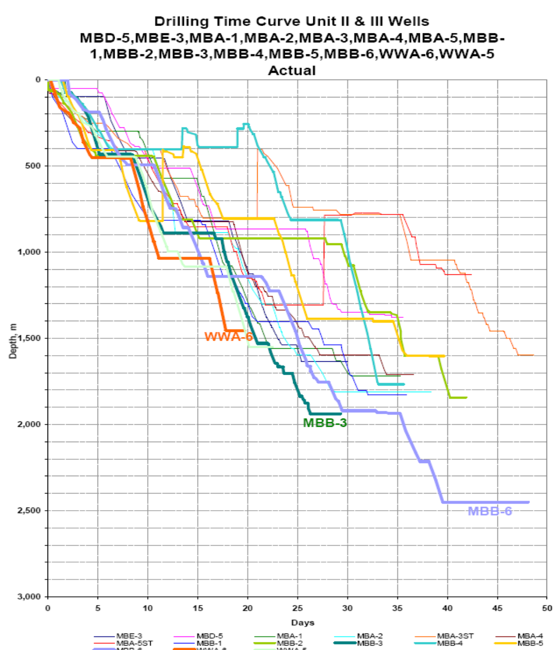


*Figure 17: 2011 Drilling campaign actual days vs depth.*

The performance of MBB-6 well brought up the level of confidence of Star Energy drilling team in dealing with high angle holes for Geothermal drilling. The WWA-6 which is the well after MBB-6 has also a complex high inclination wells with shallow depth target (not ERD).

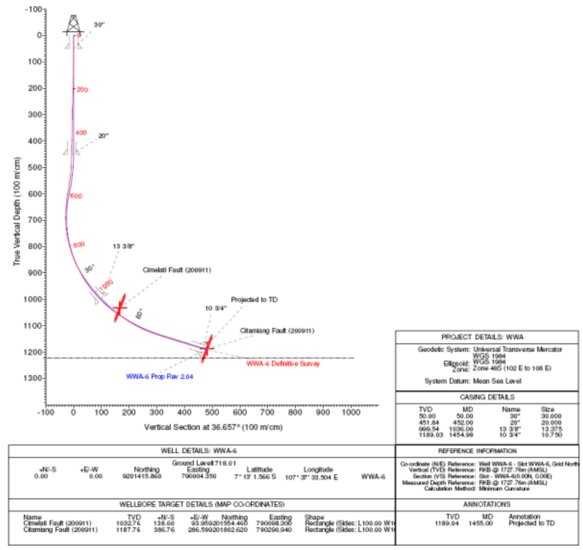


*Figure 18: WWA-6 well trajectory and completion.*

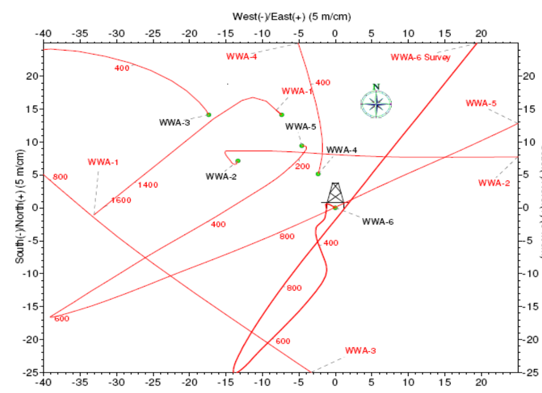


*Figure 19: WWA-6 Spider Plot.*

With the lesson learned from MBB-6, the drilling of WWA-6 was much easier. Hence, the very minimum "non productive time" (Fig.20) was achieved and considered as the other appreciable performance in the 2011 drilling campaign.

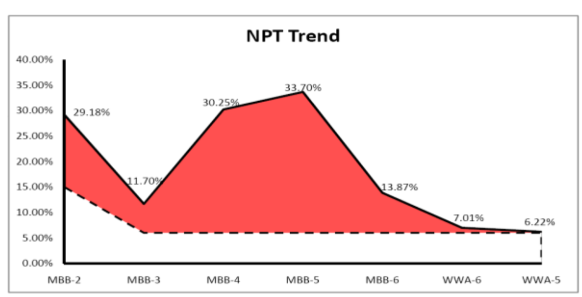


*Figure 20: 2011 Non Productive Time records.*

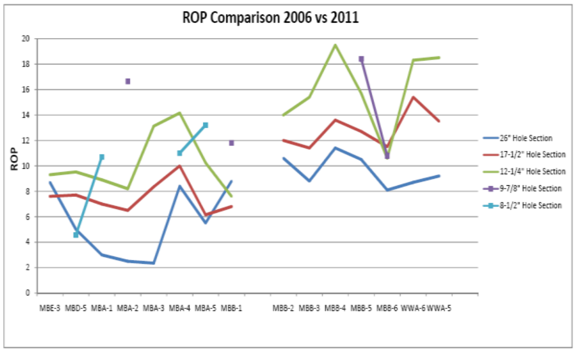


*Figure 21: Drilling rate comparison each hole section.*

Traced from last campaign in Wayang Windu drilling record, MBB-6 is the highest angle and the deepest and longest depth that was ever achieved in the area (Fig.22).

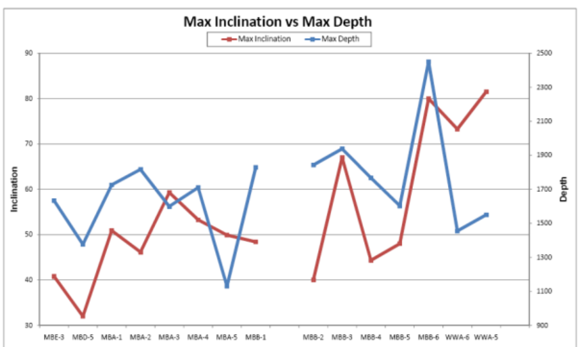


*Figure 22: Inclination vs Depth in Wayang Windu wells.*

## CONCLUSION AND RECOMMENDATION

The success of the high angle wells drilled in the Wayang Windu area is an inspiration to all geothermal drillers and developers who may just duplicate the techniques, procedures and parameters if they wish to implement a high angle geothermal well program. As of this writing, Star Energy also completeted another high angle geothermal well on WWA-5. The program was patterned to WWA-6.

As mentioned in introduction that performance will also give an impact to cost, in Fig.23 showing that in total the drilling team completed the actual cost around under 10.74% from budget.

At of this writing it can not be said though that wells that hit multiple zones intersected by high angle trajectories have better production output as wells testings still continue.

Drilling though at high anlge within the major loss zones proved that cuttings deposition is effective as it falls on the low side of the well without the risk of it going back into the wellbore. As noticed during the drilling process, there was not much of a problem that we can be concerned about as these can be overcome by the normal drilling practices, i.e., high torque which can be relieved by working the pipes, and minor overpull which can be relieved by moving the and working the string. It is worth mentioning that these high angle wells were completed ahead of schedule and below the budget. It can be surmised that proper preparation, correct information from concerned groups, i.e. subsurface and other support groups, team drilling experience and full support from management greatly contributed to the success of this endeavor.

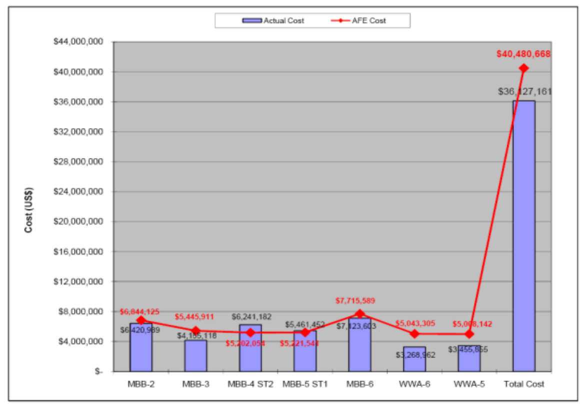


*Figure 23: Cost records (Actual vs AFE).*

Depending on the result of the well tests conducted by subsurface, reservoir and production groups on the the high angle wells, Star Energy will implement programs that will necessarily be beneficial to the interest of the company.

The drilling team of Star Energy now is meticulously documenting all of the best practices in drilling high angle wells in a multifractured zones and will continue to face all challenges that may come up during this drilling campaign.

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