D1.3 “What-If” Scenario report

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Acronyms

AI	Artificial Intelligence
BHA	Bottom Hole Assembly – The section of the drill string from the bit to the drill pipe. The BHA, is designed to include any specialised tools, technologies etc., that allow the well to be drilled efficiently.
BUR	Build up Rate – term used to define the radius of curvature in a non vertical well
DA	Data Analysis/Data Analytics
DDR	Daily Drilling Report – a record of all operations over a 12 or 24 hour period
DST	Drill Stem Test – operation where the pressure in the drill pipe is lowered, in order for gases/fluids from the formations can flow, for analysis
EOWR	End of Well Report – a full and final report on all activities associated with a well.
LCZ	Lost Circulation Zone – zones where the drilling flush is lost to the formation.
LTI	Lost Time Incident – loss of operational time (rig shut-down), usually due to personnel having an accident or a dangerous occurrence takes place that requires investigating.
LWD	Logging Whilst Drilling – in-hole equipment that logs formations being drilled
MD	Measured Depth – the total length of the well from surface to bottom
ML	Machine Learning
MWD	Measurement Whilst Drilling – records downhole data, azimuth, position etc as drilling progresses.
NPT	Non Productive Time – all the time when the bit is not on the bottom of the well and drilling (May also include LTI).
PP	Pore Pressure – Pressure due to compaction in the interstices of formations (Either fluids or gases). PP above hydrostatic may cause issues with drilling.
ROP	Rate of Pentetration / Rate of Progess (This may either be “instantaneous drilling rate” or overall Time (Time/Depth plots)
RPM	Rotating speed of drill bit
TVD	True Vertical Depth – the depth difference from the top of the well to the base of the well, vertically, in order that hydrostatic pressure can be calculated for well control.
UCS	Unconfined Compressive Strength – Defines rock strength as derived from laboratory tests
WOB	Weight on Bit – the load applied to any drill bit to effect drilling

Executive Summary

Reducing the risks associated with the drilling of deep geothermal wells is at the forefront of the sectors' thinking. As with almost all walks of life, the collection, analysis, and use of data are becoming so important, possibly to the detriment of progress.

Will data override and remove the ability of the human intervention to optimise operations? Can data and people work in harmony to maximise the chances of successful outcomes?

The OptiDrill Advisory system aims to achieve this, through a purpose-designed downhole sensor system that can transfer drilling data in real-time to the drill floor, assisting the driller in making better informed decisions and learn from the current data for the enhancement of the advisement in the next application.

Machine Learning-based models will be trained with historical drilling data, from as many geological settings as possible, with intense data analytics that will feed into a Graphical User Interface, to support drilling decisions.

However, the OptiDrill team are fully aware of the shortfalls of data, its quality, quantity, and availability across open platforms. Therefore, they have therefore committed to an extensive “What-If” analysis, which will continue throughout the project's lifetime and into its commercialisation. Without doubt, this “What-If” analysis document will see many iterations as the project develops over its duration and for many years into the future.

1. Introduction

"What-If?" has become a widely used planning and mitigation strategy tool, particularly when we are becoming increasingly reliant on data-driven decision making. Given the volumes of data we now have access to in our daily lives and the growing sophistication of Machine Learning and Artificial Intelligence algorithms, having checks and balances in place to anticipate and rationalise the unexpected is key to avoiding costly, possibly catastrophic, mistakes.

Decision Making Tree Diagrams have been in existence for a long time and are still the cornerstone for many industries, and in some ways to many people, although more likely to be a mental process as opposed to a drawn diagram.

Whilst the OptiDrill project is focused on utilising historical well data and the development of an advisory operating interface with drill string sensor technology, it recognises the fact that "What-if?" scenarios need to be incorporated within the training and validation data sets. This may be where there is a challenge of the data or where data is created, based upon operational inputs and scenarios, gained through experience. This will continually reinforce the OptiDrill advisory system.

The OptiDrill team encompasses wide ranging drilling and sub-surface expertise, working alongside data analysis and Machine Learning specialists, underpinned by sensor system developers, which will lead to a robust drilling advisory system, in real-time at the rig floor, aiding and guiding drill crews to make better and more informed decisions, resulting in reduced well problems, process optimization, and lower risks.

In order to rank the significance of the impacts of both tangible and intangible occurrences, not always captured within digital or analogue data, this report will aim to establish something similar to a Failure Mode and Effects Analysis (FMEA), used elsewhere in industry to understand chain-reaction events.

2. Chapter 1 – Understanding the Drilling Operation

Drilling deep wells, for whatever purpose, involves many stages, from concept, through to completion. In many ways, similar to a child growing up, when taught incorrectly, mistakes will continue to be made, possibly with increasingly onerous impacts. For example, not tying their shoes correctly can lead to trips on flapping laces, whereas not heeding the warnings of poisonous substances can lead to severe illness or possibly death.

So, the more extensive the planning of a drill operation is, the more likely it is to succeed and achieve all its key objectives. Within the OptiDrill Advisory system, the Machine Learning will work with the digital data from drilling parameter recorders and analogue data from the daily drilling reports, which often overlap or sometimes contradict each other. It is these intersections where the "What-If" analysis will play its part, bolstering, challenging and possibly dismissing data as unreliable. This is particularly poignant around Lost Time Incidents (LTI's), which involve injury to personnel and damage to equipment and may not always be correctly recorded or reported, either through incompetence or occasionally through misleading information being supplied.

At this point, defining the operational process helps to understand the connection to each and subsequent stages:

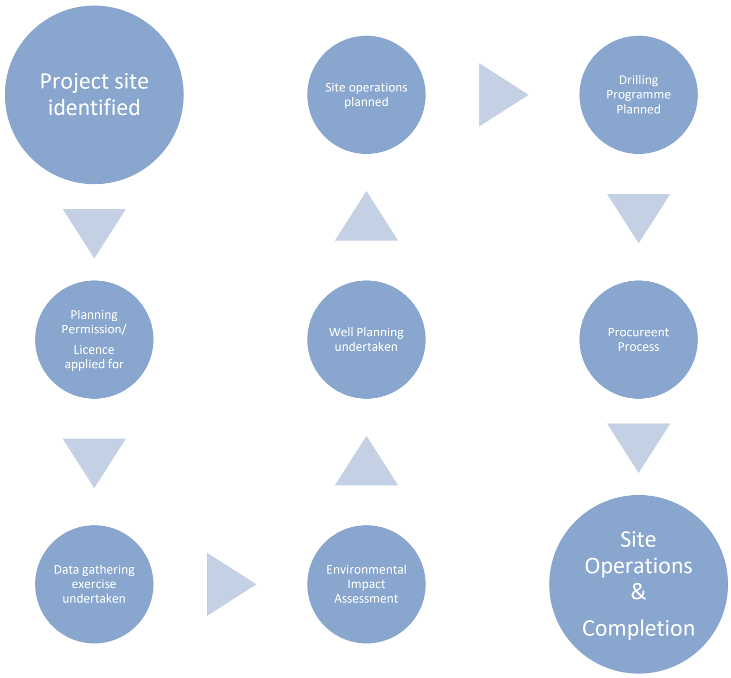

Figure 1 Drilling operational process stages

The success of a drilling programme hinges on all the above points being completed as thoroughly and accurately as possible; miss something of importance at any point, and the drilling programme will be seriously impinged.

Whilst the OptiDrill Advisory system is primarily focused upon the final point, it needs to be understood that no matter how much training data has been gathered from other well operations, if there are weaknesses within the chain of events, then the project will fail. So challenging data at every stage is an extremely important step to ensuring the OptiDrill Advisory system delivers the best returns to all stakeholders.

2.1 Project Site Identified

There can be a number of reasons a project site is selected – locality to end-users, ideal geological conditions based on available information, suitable area of development, site conditions (level, no overhead or buried services etc.), political drivers, and so on.

What-If, however, the project site is less than ideal, and it is not recognised until well into the actual site operations? It is very likely that the project will still push ahead, but the drilling-related data may not be as good or valuable, as it could have been.

So, if we have historical drilling data from 100 sites and 4 of those sites are not ideal, what does that mean for the data analysis that the Machine Learning will undertake?

The planning/licencing stage is unlikely to have a significant impact on the drilling-derived data. However, caveats might skew information, such as permitted noise levels preventing 24/7 operations, requiring additional tripping back to the casing shoe, etc. For data to be robust, it does need to be thoroughly understood, analysed, and contextualised.

2.1.1 Data Gathering

Typically, where a project is within a particular geological setting and where other projects have taken place, there will be some good historical data available, and if the operator has already drilled wells nearby, then they will have an increasingly good information to base further planning on.

The OptiDrill Advisory system is planning to draw on getting as much of this data for initial learning progress and then continually learn from newly derived data, combine the gained knowledge into a unified system, and, with strong analysis, become increasingly important for OptiDrill users to benefit from better-informed drilling decisions.

2.1.2 Environmental Impact Assessment

All drilling operations must ensure that they do not have a negative impact on the environment, both on the surface and within the sub-surface. Geothermal Energy's aims are to improve the availability of low carbon electricity and heat, so it makes complete sense to not impinge upon the environment in other ways.

So, understanding what constraints have been placed on operations can impact the ways wells are drilled, which may not always be optimal, meaning that such things need to be understood and taken into consideration when analysing the data that is to be used for the training of the OptiDrill Advisory system.

2.1.3 Well Planning

A pivotal stage of the whole operation, get the planning wrong, and the entire process becomes seriously impinged.

What-If, the well plan misses certain geological features, such as sills and dykes, within sedimentary formations, which requires a very different drilling methodology, but due to the unavailability of alternative equipment, drilling continues at a hugely reduced rate of progress which will give poor data, related to equipment selection, overall progress is compromised and gives skewed data. What-If another well is planned nearby, assuming there will be a sill that requires a different drilling method to avoid significant (cost/time) losses accrued on the previous well and then no sill is encountered? Again, losses will be accrued, as additional equipment would have been purchased and not used, casing programmes may need to be changed, fracture gradients and pore pressure gradients may be very different requiring engineering changes etc.

Therefore, well planning must be as flexibly rigid as it can be.

2.1.4 Site Operations Planning and Drilling Programme

Site operations will be governed by all of the previous stages. They will influence the drilling programme in multiple ways, especially when 24/7 operations are not permitted or when the site footprint is quite small and logistical planning becomes crucial to avoid non-productive time and/or the well degrades due to various factors.

The drilling programme is a roadmap for the success of the well.it allows the subsequent operations to move forwards, and the well to be drilled as best as it can be. What-If then, the previous steps have been based on misinterpreted data (computer or human), and the drilling programme is compromised, requiring several changes, with inherent delays and costs. Of particular importance, is the fact that the drilling programme forms the basis of selecting a contractor who will use the programme to cost the operation in order to win the contract. It is straightforward to see how errors here can lead to accumulating costs, not accounted for at the initial stage(s) of each project.

2.1.5 Procurement

Totally dependent upon all previous stages of the process and entirely influential on the overall success of the drilling and completion stage. Often, procurement is undertaken by non-drilling specialists who are given a list of requirements and then do their best to fulfill everything at the lowest possible cost, with optimal delivery times and favourable terms. Planning and procurement are often confrontational with one another, but both serve vital roles, and both are exposed to making mistakes.

2.1.6 Site Operations and Completion

The sum of all the previous steps and once completed a vital source of new data and lessons learned, which can better inform subsequent projects.

Machine Learning and Artificial Intelligent applications will help to enhance the understanding of new data, analyse it with consideration of the gained knowledge from the historical data, and turn it into a predictive model, but What-If….?

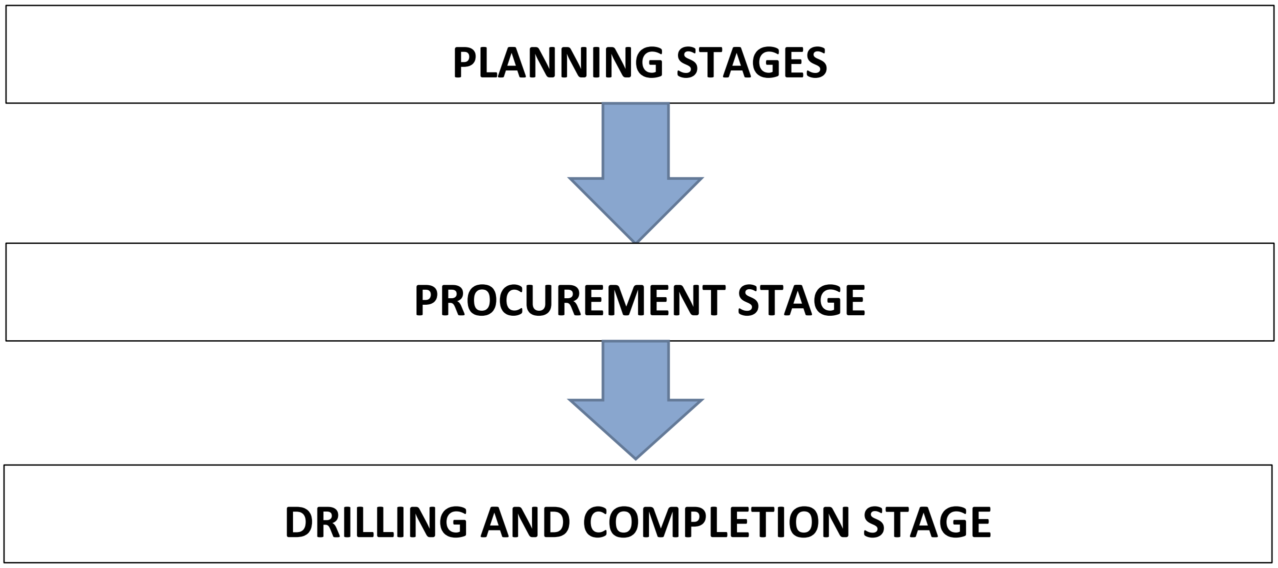

Figure 2 Site operations and completion main stages

3. Chapter 2 "What-If" Scenarios

As shown in the previous chapter, there are many points where things can go wrong, and at the same time the data produced needs to be fully understood and analysed.

Some "What-If" scenarios can be planned in advance however many cannot while even with the utilization of the best computer models, there are always things that cannot or may not be anticipated.

A good example of this in the non-drilling world is the current Covid pandemic, where governments make decisions based on data, which is often lagging behind what is actually happening and therefore possibly incorrect, or they make decisions before the data is fully available/analysed and make a decision that turns out to be detrimental to the economy. What-If they had waited longer or acted earlier, would the outcomes have been better?

So, data is very good at determining what happened, why it happened and in many circumstances predicting what will happen, insofar as establishing common patterns across multiple data sets, and then using Machine Learning and Artificial Intelligence, at much greater rapidity than human analysis is capable of.

Increasingly, we are becoming highly reliant on data-driven solutions to get us through life on a daily basis; satellite navigation is a prime example and is, in lots of ways, what we are trying to achieve with the OptiDrill Advisory system. When you type in an address, the SatNav will give you a choice of routes – quickest, shortest, etc. The driver then chooses the route that suits them. Most SatNav systems now have live update features that help the driver optimise his journey by avoiding heavy traffic areas, accident areas, etc. These features though, still put the driver in charge. What-If the SatNav system, anticipates that there is heavy traffic ahead and suggests an alternative route, yet the driver can see that the traffic is moving freely? What-If the driver sees traffic moving freely, yet it becomes stationery 1km ahead, causing a delay of an hour to their journey? Commuters on a daily basis, may just accept that they will have a hold up. If we followed 100 drivers for 4 weeks and 90 of them accepted the delay and 10 of them took a variety of alternative routes that saved them between 2 and 20 minutes each day, with 3 using the same amount of energy, but only saving 2 minutes on average, 5 using 5% more energy and saving 10 minutes, but getting to lower cost parking spots, 2 using 10% more energy and saving 20 minutes, but getting free parking (let us assume they are electric cars), what would be the optimal choice?

Transferring this analogy to our drilling conundrum and we begin to see how complex any drilling advisory system needs to be. It cannot just be built around data alone, it must incorporate "What-If" scenarios that help to train the Machine Learning component and develop the Artificial Intelligence that will assist the drill crew optimise their drilling programme, even when there have been errors within the planning and procurement stages.

Before drilling even begins, we may have several "What-Ifs" that could affect the overall success of the well. These factors need to be addressed so that the drill crew can best use the real-time data from the OptiDrill Advisory system.

What-If the geological prognosis for the well is different from the actual formations encountered? Perhaps the limestone has a strength higher than planned for, and the bits that were ordered, are not ideally suited for the drilling of such formation. The supply of optimal bits will take six days on average, so does the contractor/operator stop drilling and wait for the new bits, or carry on until the new bits arrive, although bit life is only 30% of optimal, so additional tripping time will be incurred over the six days?

What-If the driller has drilled twenty previous wells in a particular basin, all with the same in-hole tooling set-up and circulating system, but the OptiDrill Advisory system, has data from wells with similar lithologies, which suggest that changing the bit (for example) and increasing the weight-on-bit, will result in an overall increase in Rate of Progress (this is preferred to rate of penetration, as often drillers try to drill too quickly, which is detrimental to the overall rate of progress, which influence all parameters of the drilling operation). What-If the data from the twenty wells drilled sub-optimally is used for training data for the OptiDrill Advisory system, because no other data is available. Will that result in wells drilled elsewhere suffering? If we put rubbish in, will we get rubbish out?

The problem with all drilling operations, is one never really knows what the issues are until one has finished the well. A key point to take on board, that no two wells are ever the same – there will always be subtle differences. Drilling is as much an art form, as it is a science. So, aside from actual data, the “what-ifs” will be hugely informative for a drilling optimisation system. Hence, we will also incorporate an extensive “what-if” matrix that will benefit the ML process and not suffer from the auto-drill systems' current constraints. This illustrates an example what-if scenario for OptiDrill Advisory system.

Below is a hypothetical drilling problem, although based upon an actual well:

Table 1 Example what-if scenario

Case	Description
a) Scenario	A geothermal well is being drilled in carboniferous limestone, which is massively bedded, with widely spaced bedding and fracture planes that have been infilled with clay and silts, as well as some calcification. Permeability is relatively quite low. Hydrostatic pressure is 9.8 kPa/m; Effective overburden pressure is 15.8 kPa/m. Rock UCS is 56 MPa The section being drilled is from 2,800m to 3,300m at 8 1/2” diameter. 9 5/8” Casing is set at 2,600m. Drill pipe is 5 ½” FH 24.70Lbs/ft S-135. BHA is Fluid Hammer, with PDC enhanced semi-ballistic bit, Near Bit Stabilizer of 9” diameter, 2 x 8 ½” x 3 ½” Collars, Stabilizer, 5 Collars, Stabiliser, 10 Collars, Drill Pipe. Fluid is KCL with added Polymer.
b) What-If Scenario	1. “What-If” Rate of Penetration (ROP) decreases from 12m/hour to 9m/hour, measured over 15 mins. 2. Pump flow rate is 800 Litres/min 3. Pump pressure is 140 Bar – Pop-off set at 225 Bar 4. Pit level monitors record a reduction in tank volumes of 5,400 Litres measured over 15 mins 5. Hydraulic system notes an increase in torque from 13,558daNm to 16,600daNm 6. There is an increase in standpipe pressure from 140 Bar to 190 Bar 7. Depth indicator reads 2,970m 8. MWD shows TVD @ 2,900m
c) Driller’s Response	1. First reaction is the bit is blocked 2. Bit is lifted off bottom by 1.0m 3. Driller note’s 5% over-pull 4. Standpipe pressure drops to 140 Bar after 5 mins 5. Pit levels drops by 2,800 Litres 6. After a further 5 mins, the driller runs back on bottom 7. ROP is 10 m/hour after 5 mins 8. Flow rate remains steady at 800 Litres/min 9. ROP starts to drop off again 10. Flow returns slow dramatically 11. Driller lifts off bottom again 12. Standpipe pressure stays at 140Bar 13. Torque starts to climb 14. Driller decides bit is blocked again 15. Driller decides to pull the bit 16. 10 pipes are pulled, although driller notes overpull each time 17. As they try to pull the 11th pipe, the string becomes stuck. 18. They spend 3 hours back reaming the pipe, before it comes free. 19. Driller realises that the hole has collared and causing pipe to “hang” resulting in low bit weight.

	20. Driller decides not to pull the rest of the drill string but circulates a clay inhibitor additive for 3 hours. 21. **After 8 hours of Non-Productive Time (NPT) the bit is back on bottom drilling at 12m/hour.**
d)	22.
e) Response with OPTIDRILL	1. At 2, 870m bit sensor notes that there is less resistance from the formation 2. Driller's panel shows an alert. 3. Driller lifts off bottom 4. Flow returns are monitored for 15 minutes and hydratable clays are seen in the mud returns. 5. Driller circulates clay inhibitor 6. After 1 hour, bit is back on bottom with RPM increased from 30 to 38 7. **After 1.5 Hours ROP is 14m/hour** 8. **Total NPT is 2 hours**

The above is an example of a particular drilling problem over a section of well and how the OptiDrill Advisory system optimises the drilling parameters. There will many wells where the drill crew may miss minor tell-tale signs of problems to come, particularly those associated with the formation. Most fluid circulating systems have an annular velocity of 60m/minute, so in a 3,000m deep well, it will be 50 minutes before cuttings arrive back at the surface to be analysed by the geological team.

Whilst MWD and LWD systems have greatly decreased the time-lag and other new systems are starting to deliver information/data to the surface in real time, there is still the need for understanding the information/data to optimise the drilling process(es).

Unlike Oil and Gas reserves, which are almost always encountered within sedimentary formations, geothermal resources can range from high temperature active volcanic systems through to cold granites, meaning that a wider variety of drilling methods need to be considered or deployed to ensure wells are drilled as efficiently as possible.

Given that so many variables can affect the drilling of a well, it makes sense to try and rank them into groups and then rate their impact on the project and how the OptiDrill Advisory system will benefit and learn from new data as it becomes available. This will be a continually evolving process, as new drilling technologies bring new types of data categories, deeper wells will present wholly new geological information (temperature, rock strengths, formation characteristics etc.), changes in pore pressure will offer new challenges, and so on. The OptiDrill Advisory system will need to grow to stay State of the Art by acquiring the relevant data and integrating the lessons learned into its system

So, starting the "What-If Scenario" planning in parallel with the Machine Learning process from historical data, is an essential step to ensuring the robustness of the system. Obviously, this is a huge task and will be continuous throughout this project and beyond but will start as part of the Machine Learning process, and whilst it will focus on in-hole drilling issues, it will need to encompass all of the What-If scenarios, that may affect the drilling process either through process optimisation or early problem detection.

The geothermal energy community place a great deal of emphasis on drilling cost and drilling risk, but where does the risk manifest itself? What-If the drilling contractor had accurate geological information, the correct bits selection provided, pore pressure and fracture gradients analysis that allowed the driller to have perfect fluid weights, reservoir parameters that fulfil the operators/end-users needs, would we then have no drilling related risks? Probably not, but the OptiDrill Advisory system aims to reduce the risks in real-time, and hopefully, will impact the planning and procurement phases to improve the number of positive outcomes.

4. Chapter 3 Chain of Events and Consequences

It should be noted that the following table will be a live table throughout the project and will be updated constantly through encountering new datasets and analysis of possible what-if scenarios within them.

Table 2 Possible What-If scenarios, Consequences, Impacts, and Mitigations

Planning Stages				
What-If?	**Consequence**	**Impact**	**Mitigation**	**OptiDrill**
The geological prognosis is not accurate	Inefficient drilling process, possible failure of well.	Possibly severe	Better geophysical information/better desk study planning	Will strengthen the drilling data from previous wells
The procurement process is based upon incorrect geological prognoses	Possible failure of well. Increased NPT. Possible risks to the environment	Possibly severe	Better geophysical information/better desk study planning. Engagement with suppliers.	No input
The drilling programme is based upon incorrect geological prognoses	Possible failure of well. Increased NPT. Additional costs incurred	Possibly severe Definite increase in well costs	More robust planning. Contingency planning.	Real-Time Data will flag up issues at an earlier stage of the drilling process, allowing for contingency planning to implement.
Drilling Stages				
The driller fails to notice warning signs of problems	Increased NPT, possible well issues	Mildly Severe to Severe	Supervision	Flags-up issues and makes recommendations
Change of shifts don't fully share information	Increased NPT, possible LTI's, possible well issues	Possibly Severe	Rigorous hand-over procedures	Constantly records drilling data in real-time, fully accessible to all
Lithology parameters change outside of the geological prognoses	Increased NPT, possible well issues	Mildly Severe	Will vary according to the nature of the change(s) – pore pressure, fracture gradient, elevated temperatures etc.	Real-time data and ML lithology prediction will better inform decision making to minimise issues

What-If?	**Consequence**	**Impact**	**Mitigation**	**OptiDrill**
The bit type is not chosen optimally	Reduced drilling efficiency, possible issues	Mildly severe	Better planning. Change the drilling type	Real-time optimization module will suggest possible ways to optimize through bit change or process parameters
The drilling rate is not optimum with efficiency reduction	Reduced drilling efficiency, possible issues	Mildly sever	Bit change	Real time recommendation of the OptiDrill system can show the need to change the bit
The drilling rate is not optimum	Reduced drilling efficiency, possible issues	Mildly sever	change process parameters	Optidrill Real-time optimization of process parameters suggesting a set of optimized drilling parameters
The well stimulation / completion process can not be monitored correctly	Reduced final well productivity. Unsuccessful stimulation job.	Mildly Severe to Severe	Better monitoring and analysis methodology for micro-drilling and stimulation technologies	Optidrill monitoring and well completion analysis system will aid the driller to conduct the process successfully

5. Conclusions and Recommendations

The OptiDrill Advisory system project will combine State of the Art technology, with an understanding of how to blend pragmatic thinking with data driven processes, that will assist deep geothermal drilling operations, become more cost effective and will encourage the uptake of geothermal resources as part of the low carbon energy transition.

As geothermal is a baseload resource, for heat and electricity generation (where the enthalpy is sufficiently high), a very low carbon footprint and does not require other resources for storing intermittent energy production, it makes eminent sense to include it as a cornerstone of the low carbon energy mix.

Wind turbines and solar photovoltaics were initially very expensive, heavily subsidised and were viewed as being of marginal importance for climate change mitigation; today they are the prime source of power supply in many countries. But they have an increasingly significant environmental impact (visual, disruptive to wildlife and flora, geo-political considerations associated with manufacture etc), use substantial amounts of rare or difficult to obtain mineral resources and quite possibly a repetition of the many mistakes made in the first industrial revolution.

Uniquely, geothermal can supply heat directly from the resource and as a large percentage of our energy usage is for the heating or cooling of buildings, why increase inefficiencies by converting one form of energy into another (e.g. wind power into electricity) and then converting it yet again for heating or cooling?

However, deep geothermal drilling is fraught with problems, which does not easily attract commercial investment and outside of certain high enthalpy volcanic regions (e.g. Iceland, New Zealand, Pacific "Ring of Fire" Regions) is not generally part of utility companies' portfolios. How can this be changed?

What-If we can reduce drilling risks and better guarantee outcomes? Will these two factors alone start to change institutional thinking?

The one thing we can be certain of with geothermal as an energy source is that the resource from where it is drawn, will maintain stability for many millennia, whereas the vagaries of climatic conditions may change drastically in a very short time, rendering many of them marginal, at best.