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D1.2 Characterisation Report

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[1] Dissemination level security:

PU – Public (e.g. on website, for publication etc.) / **PP** – Restricted to other programme participants (incl. Commission services) /

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CONTENTS

1. EXECUTIVE SUMMARY

This deliverable sets out the required characteristics of the in-hole equipment in order to achieve the target of reducing geothermal well costs, particularly those associated with drilling into high strength formations, found at depth and to withstand the rigours such formations present, including elevated temperatures and pressure.

Currently, the geothermal industry still leans towards Oil and Gas drilling methodologies and technologies, which can come with a high operating cost, when the price of those commodities is high and available rigs are minimal. In addition to this, most hydrocarbon drilling is within lower strength sedimentary or metamorphic formations, which present different problems from those encountered by deep geothermal projects.

Whilst, there is a growing number of “geothermal drilling” companies, the industry still lags a long way behind the number of rigs drilling for oil and gas. Geothermal drilling research is gathering pace, but relatively little research and development has focused on breaking and moving rock efficiently.

As the majority of drilling cost is time related, then ensuring that time is not wasted, is a giant stride forward in reducing geothermal exploitation. When the drill bit is operating, money is being saved. So new advances need to concentrate on tooling that is robust, reliable and does not require to be tripped out of the well until each hole section has been completed. It is well known that Down The Hole (DTH) hammer drilling is very effective in higher strength formations, but the current air and water powered offerings have limitations for exploitation of deep, high-temperature geothermal resources.

This report characterises how current methodologies can be improved upon and through the introduction of wholly new technologies and processes, a completely novel way of exploiting deep geothermal heat and power will be delivered.

2. OBJECTIVES MET

The deliverable contributes towards the following work package objectives and should be read in conjunction with the Rheology testing report (D1.3, submitted M5)

- To characterise the geothermal drilling environment which will be used to design criteria for materials and coating and to set up the simulated laboratory geothermal.

3. CURRENT DRILLING CHALLENGES

This report sets out to define current industry standards for the drilling of deep geothermal wells and the characteristics required to be incorporated within the Novel System under development by the Geo-Drill Consortium.

One of the key issues of current deep geothermal projects, is the need to utilise technology and methodologies from hydrocarbon exploration and production drilling, which have historically high costs attached to them, although with waning demand (driven by climate change awareness) this is decreasing somewhat. So the geothermal industry requires a “bespoke and fit-for-purpose” drilling system, capable of withstanding high formation temperatures, high strength rocks, high pressures (depth related) and aggressive formation fluids (typically brines). At the same time, this new drilling technology must be reliable, simple to operate and be cost-effective in the drilling process.

Whereas most hydrocarbon reservoirs are within sedimentary and metamorphic formations, the greatest potential for sustained geothermal production lies within high strength igneous rocks, with good thermal properties and heat profiles. Such formations pose particular problems not generally associated with deep drilling and respond better to high impact percussion drilling, rather than the crushing or shearing methods that tricone roller or fixed cutter drill bits use. Breaking the formation into chips, rather than grinding, is both more efficient, in terms of energy input, and quicker.

With the increasing demand for “base-load” (heat/power production that has a constant and predictable delivery profile), that is low carbon and close to centres of populations, deep drilling into high strength/high heat formations is set to rise, dramatically. Unlike oil and gas, heat energy is not easily transported great distances and as the predominant energy usage is for heating, it makes eminent sense to avoid further energy losses due to converting heat into electrical energy, and converting it back to heat. This is particularly relevant for District Heating Schemes (DHSs), where heated water can be piped to domestic and industrial properties and recirculated to be reheated by the rocks at depth. Geothermal drilling systems need to have the following characteristics:

- The ability to drill in micro-crystalline rocks, with high strengths, at rates of penetration that are substantially higher than conventional rotary drilling;
- The ability to withstand abrasion;
- The ability to withstand prolonged stress loading;
- The ability to move cuttings, produced by the drilling, long distances to the surface;
- The ability to cope with changeable down-hole conditions, without the need to trip out of the well;
- The ability to provide real-time information from the bottom of the well to the "driller", so that the whole operation can be constantly optimised;
- The ability to be integrated with existing surface equipment, to minimise CAPEX inputs to the industry.
- Be simple to operate, be cost effective and readily available;
- Whilst all of the above are reasonably achievable, individually, the challenge of combining them all together is a substantial challenge, but through the adoption of a new approach to solving the issues, holistically, a whole new era of lower cost geothermal wells are within reach.

4. CHARACTERISATION OF GEOTHERMAL DRILLING

In order to assess the current industry capabilities, an extensive desk study was undertaken. Additionally, a consortium wide Failure Mode and Effects Analysis (FMEA) was carried out (See D1.1 FMEA report), in order to steer the project and identify key issues from the base of the well back to the surface.

For ease, this section has been arranged into component parts, from the base of the well operation to the surface, highlighting the current weaknesses and strengths, and the characteristics required by the NOVEL technologies under development in this project.

DRILL BITS

Rotary Tricones (Figure 1): A tried and tested methodology for drilling in all rock types:

- Milled Tooth Insert Tricone.
- Ideally suited to softer formations and unconsolidated sands and gravels.
- Tooth wear, erosion of body structure and bearing damage, due to incorrect Weight on Bit (WOB) are common causes of premature failures.
- Proper selection of bits, matched to formation and correctly used can result in good life-cycles.
- Cone failures can lead to expensive fishing operations.
- Typical rates of penetration (ROPs) in formations with strength greater than 15MPa are 10 – 15m/hour, dependent upon hole diameter.

Figure 1 Rotary tricones

Tungsten Carbide Insert (TCI) Tricone (Figure 2)

- As the name implies, TC buttons are inserted into the cone bodies. Insert shape and size can be selected depending on the formations to be drilled. Typically, hemi-spherical inserts are used for harder formations, chisel inserts for softer.

- Ideally suited for formations ranging in strength from 30 MPa to 150MPa. Although used in rock types with high compressive strengths (up to 350 MPa) the ROPs are low and cost of bits is high. Life-cycles can be quite low, resulting in additional non-productive time (NPT), related to tripping times in and out of hole. Cone failures can also add to NPT.
- Typical ROPs range from 1.0m/hour to as high as 20m/hour.

Figure 2 Tungsten carbide insert tricone

Fixed Cutter Rotary Bits (Figure 3 - Step Type Drag Bit, courtesy of CCE-Sondametal))

- Ideally suited to softer formations, cohesive formations, sands and gravels.
- Low cost and reasonable life expectancy, but very limited use in formations with strength above 8-10 MPa.
- Whilst bit diameters up to 26” (660mm) are available, the optimal sizes range from 3 ½”(89mm) to 8 ¾” (220mm).
- Typical ROPs range from 5m/hour to 15m/hour.

Figure 3 Fixed cutter rotary bit

Polycrystalline Diamond Compact (PDC) Fixed Cutter Bits (Figure 4)

- In essence these bits are the same as fixed cutter rotary bits, with the exception that they perform exceedingly well in non-clastic and meta-sedimentary formation types.
- Blades are faced with polycrystalline diamond inserts, which shear formations. Can be configured according to rock type to be drilled (number of blades, insert sizes/distribution etc.) and are particularly effective for steering operations with Positive Displacement Motors (PDM).
- Drawbacks are: relatively high cost and limitations in strong micro-crystalline rocks and stronger clastic formations.

Figure 4. Polycrystalline Diamond Compact (PDC) fixed cutter bit

PDC Impregnated Bits (Figure 5)

- Similar in nature to PDC Fixed Cutter Bits, the smaller diamond structure, which is impregnated into the bit body matrix, allows hard and abrasive formations to be drilled.
- Speciality bits, that permit rock cores to be recovered, are often impregnated with diamond chips.
- Can be used with steering systems.
- Relatively high cost and low ROPs, but can cope with hard/soft bands. Additionally, can require higher rotation speed to drill optimally.

Figure 5 PDC Impregnated Bit (courtesy of SLB Schlumberger)

Down-the-Hole Hammer (Figure 6)

- Tungsten carbide buttons are inserted into a bit body, for use with a hammer (air or water powered). The hammer provides high impact energy to the bit, resulting in the rapid breaking of rock into chips, making this methodology ideally suited for stronger rocks.
- Air powered hammers have achieved depths of over 5,000m, but are affected by formation fluids (annular backpressure) and require large volumes of high pressure air (large horsepower input). Unstable formations can also be an issue, as there is no “hydrostatic” pressure to counteract pore pressure, which can lead to wellbore instability. In Hot Dry Rock (HDR) geothermal system drilling, high ROPs can be achieved, resulting in lower drilling costs.

- Water powered hammers, offer all of the benefits of air, but allow for drilling in formations where formation fluids and high pore pressures are an issue. Drawbacks are the requirement for clean water and hole diameters need to be close to drill pipe diameters, to ensure sufficient uphole velocity for cleaning the cuttings out.

Figure 6 Down-the-Hole Hammer

Figure 7 compares the ROP for different drilling methods as a function of the unconfined compressive strength (UCS) of the formation. Figure 8 compares the price and life (in terms of average length of well drilled before replacement is needed) for different drill bits.

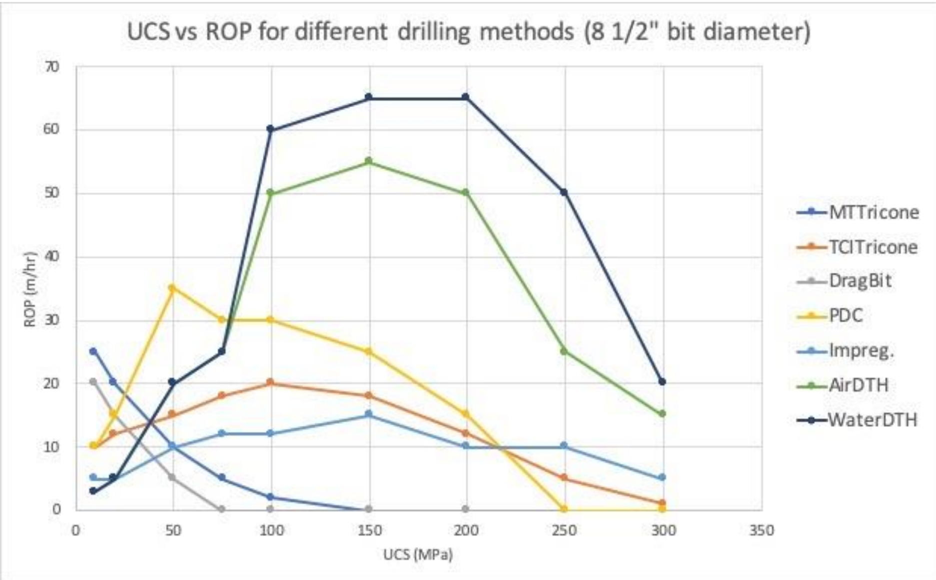

Figure 7 Comparison of drill bit performance (data based on Geolorn Drilling Projects: 2010-2019)

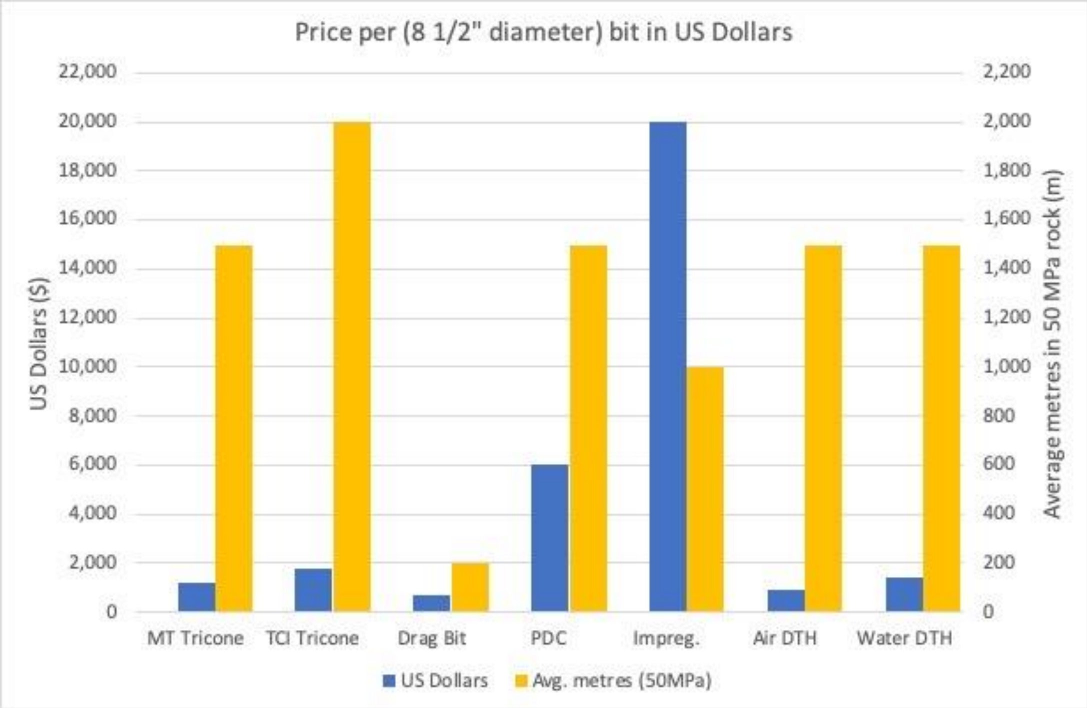

Figure 8 Comparison of drill bit price and life (information from Geolorn and generic industry data)

Figures 7 and 8 show that for the hard materials (micro-crystalline rocks or higher strength metamorphic formations) that must be drilled for deep, high-temperature geothermal wells, DTH hammers are cost-effective and provide higher penetration rates than rotary bits. DTH hammers have therefore revolutionised the drilling of hard rocks (>50MPa. They are currently split into two main types:

- Air Powered
- Water Powered

Whilst there have been developments with “mud” powered hammers, their usage has been very limited.

Table 1 Comparison of air- and water-powered DTH hammers

Parameter	Air-Powered	Water-Powered
Maximum Depth/Diameter	5,000m / 150mm (4,250m achieved at 311mm, although some issues with hole cleaning)	Unproven/216mm
Estimated Power Input (horsepower)	3,000	600
Hydrostatic Annular Pressure (assuming no formation fluid and no allowance for change in density due to cuttings)	0	0.43psi/ft 0.009836MPa/m
Optimal Uphole Velocity (m/min)	1,500	60

Parameter	Air-Powered	Water-Powered
Maximum Operating Temperature (°C) (Static Formation[1])	1800 [2] (modified seals)	1500 (estimated)
Maximum Size of Solid Particles [3] (Tolerance) µm	0	7
Foam/Polymer Additives (non-solids) (for flushing assistance)	Yes	Yes
Average Cost/m (Hammer & Bit)[4] 100MPa UCS 216mm	€ 0.40	€ 0.55

[1] The Static Formation Temperature, will always be higher than the Circulating Temperature, so tools can be operated in formations that may have high geothermal temperatures, as long as circulation is not stopped for a prolonged time period and the formation allowed to recover.

[2] Care needs to be exercised when using air in high temperature zones, with air flush, as the potential for "flash boiling" is a serious risk, should water be suddenly encountered at depth.

[3] Suspended solids seriously affect the life-cycle of internal hammer components.

[4] Cost for hammer and bits only, based on 10m/hour penetration rate

DRILL STRING COMPONENTS

The drill string is the umbilical between the surface and the bottom of the well. It has to perform a large number of functions and is subjected to numerous stresses and strains. Key functions include:

- Provide rotation to the drill bit.
- Carry the flushing medium from the surface to the base of the well.
- Resist buckling, stretching, bursting and collapsing.
- Resist wear due to abrasive fluids, internally and externally.

Key characteristics for drill string components:

- High torsional strength.
- High tensile strength.
- Ability to cope with cyclical stressing.
- High strength to weight ratio.
- Robust tool joints, which resist galling without the need to coat with expensive (and possibly toxic) lubricants.
- Low co-efficient of friction.

DRILLING FLUIDS

Like the drill string components, the drilling fluid has to perform a number of tasks, often requiring complex responses to constantly changing parameters. Drilling fluids can also be a major cost component of a deep geothermal well, especially when high fracture zones are encountered, resulting in lost circulation (i.e. the fluid pumped through the drill string fails to return to the surface). Key requirements of any drilling fluid system are:

- Non-toxic base materials, especially important when drilling through shallow freshwater aquifers.
- Ease of mixing (minimal hydration time).
- Ease of pumping (shear rate).

- High gel strength when pumping stops (to prevent drilled cuttings settling back to the bottom of the well).
- Good slip viscosity (allows for slower pumping rates).
- Low suspended solids (no suspended solids) when mixed.
- Low Specific Gravity, so as not to cause hydro-fracture (mini-frac) issues in weak formations.
- Ease of cleaning at surface for re-circulation.
- Well bore stabilisation in non-cohesive formations or when pore pressure is above hydrostatic.
- Thermally stable.

5. CONCLUSIONS

As can been seen from the preceding section, the task to develop a Novel Drilling System, capable of reaching in excess of 5,000m and coping with high temperatures/pressures, relies on combining the best of existing technologies and the introduction of wholly new processes and equipment. Given that the goal of this project is to reduce costs for high temperature and deep geothermal wells, it stands to reason that the majority of wells drilled will be in micro-crystalline rocks or higher strength metamorphic formations. DTH hammers are clearly ahead of any other methodologies, in terms of ROP and component cost, but have variable operating limitations with temperatures, annular pressures, diameters etc; there is therefore a need for an improved DTH system, able to overcome the current problems associated with DTH drilling (air and water) systems.

Additionally, introducing new downhole sensor technology that can provide wellbore condition data, to allow for continuous optimisation of the drilling process, will be a major step forwards in reducing geothermal energy costs and mitigate early stage risks associated with deep drilling projects. The FMEA, contained in D1.1, defines current system weaknesses and their resultant effects on drilling operations and feeds into this characterisation report. Additionally, the work carried out within D1.3, identifies the large amount of development still required to find a drilling fluid that fulfils all of the tasks listed in the results/discussion section and pass through a hammer without plugging or scouring the internal workings.

In conclusion, the following are the key points that will increase a successful outcome of the project:

- DTH Bits and Hammers need to match current ROP levels and lifetime expectancies. It is important to remember that ROPs cannot exceed the rate at which excavated materials can be moved.
- The DTH hammer has to allow a fluid with sufficient gel strength and slip viscosity to pass through it without failure.
- A DTH Hammer with minimum internal wear points.
- Drill string components with improved wear characteristics and reduced frictional properties, with the deployment of advanced surface coatings, to include drill pipe connections (tool-joints).
- Increased life-cycles of in-hole equipment to reduce costly trips (NPT).
- Easily integrated with existing surface equipment (rigs, mud systems).
- The development of a system that allows for real-time data transfer from the base of the well, without the risks of failure through the inability to cope with aggressive downhole conditions.
- Downhole sensors that collect pertinent data to allow drilling optimisation.
- “Energy harvest” systems that utilise the energy produced by the drilling processes.
- Make commercial sense.