Princetonlaan 6
3584 CB Utrecht
P.O. Box 80015
3508 TA Utrecht
The Netherlands

www.tno.nl

T +31 88 866 42 56
F +31 88 866 44 75

TNO report

TNO 2022 R11600

DEmonstrate Production Enhancement with LOw Cost SIde Track Drilling - DEPLOI

Public report

Date	23 August 2022
Author(s)	Frank van Bergen, Vedran Zikovic, Lies Peters (TNO), Jan Jette Blangé, Diederik Wawoe (Canopus) with contributions from the consortium.
Copy no	
No. of copies	
Number of pages	15
Number of appendices	
Sponsor	TKI Nieuw Gas and consortium members
Project name	TKI2020-01-GE DEPLOI
Project number	060.38819

Contents

1 Project information

Subsidy reference: TKI2020-01-GE

Topsector Energy, TKI Nieuw Gas. TKI New Gas contains a sub-division in gas related topics, of which Geo Energy constitutes a part. For the topic of Geo Energy one of the research themes concerns “Drilling and Completion”, which launched, under the “Regelgeving PPS-toeslag”, a specifc call for proposal entitled “Well Technology”.

Project duration:
1 December 2020 (effective start date) – 30 June 2022

Consortium
The consortium brings together a high-tech start-up company Canopus, operators and service companies with research institutes and academia from the Netherlands and EU (Table 1). The founder of Canopus is the inventor of the (Shell) abrasive jet drilling technology and he has access to the background expertise. Canopus holds the intellectual property for the directional abrasive jet drilling technology. All experiments were conducted at the Rijswijk Centre for Sustainable Geo-energy (RCSG) that has provided the full scale drilling test facilities and TNO specific expertise to conduct the tests. TNO was the project coordinator.

Table 1 DEPLOI consortium

Consortium member	Type organisation	Role in project
TNO	Applied Research Institute	Coordinator, execution of work
Canopus	Start-up	Contributor, execution of work
EBN	Large company	Sponsor
ODFJELL	Large company	Sponsor, contributor
STORENGY	Large company	Sponsor
BRGM	Research Institute	Contributor
NAGRA	Middle-sized company	Contributor
University Munich	University	Contributor
Well Guidance	SME	Contributor

Reporting
The following technical reports have been written next to this public report:

Work Package 1:	Scoping
Work Package 2:	Base system investigation part 1: Hydraulic, mechanical and magnetic design parameters of the steering sub
Work Package 3-5:	Preparation and testing of the directional steel shot drilling in the RCSG 50T drilling machine
Work Package 6:	Outlook for field experiments, including the TUM Master’s Thesis of M. Bergius titled Geomechanical Analysis of Alternative Deep Geothermal Drilling Technologies

The results of the project will further be presented in two oral presentations at the European Geothermal Congress in October 2022.

2 Public final report

2.1 Introduction

Geothermal wells need to be drilled more cost-effectively to reduce the reliance on subsidies of the geothermal industry and to improve their pay-back time. Multilateral wells can deliver the required improvement of production per reservoir and per surface location. However, drilling stable multilateral legs can be costly and new technologies are needed to bring the costs down. Abrasive jetting is such a technology that has the potential to deliver a substantial cost reduction. This technology has been under development for several years for the drilling of vertical wells and now the technology could be tested to add enhanced steering of the drilling unit to drill multilateral horizontal wells. The full functionality, including the steering functionality was ready to be tested in scale experiments, the last step before field tests can be undertaken.

2.1.1 The importance of fast directional drilling without weight on the bit

The objective of a geothermal well is to produce an amount of energy equivalent to a value exceeding the total cost of the geothermal project. As the energy content per unit of volume of hot water is much lower than the energy content of oil, the production rate corresponding to this economic threshold for geothermal is to be much higher than for the production of fossil fuels. Most hot water bearing reservoirs do not have sufficient transmissivity (permeability times thickness) such that simple low cost vertical wells would exceed that economic threshold.
Economic development of most geothermal reservoirs would therefore require a much better reservoir contact than reservoir sections with a bore hole with a length comparable to the thickness of the reservoir. Nature shows tree root structures and blood vessel structures as examples of efficient drainage structures with low draw down pressure and high surface contact: these structures are multilaterals covering a large reservoir volume. And ‘higher level’ branches having somewhat smaller diameter.
Note that multilaterals for well construction for oil and gas production have the disadvantage of early ‘water-breakthrough’. This is obviously not an issue for geothermal developments.
The challenge for geothermal is to construct multilateral structures entirely within the reservoir at low cost.
Conventional hole making removes the rock mechanically by, for instance, Polycrystalline Diamond Cutter (PDC)-bits. A 15 cm diameter bit requires typically 5,000 to 10,000 kg weight on the bit and the correspondingly high cutting force requires the drilling assembly to be very stiff. As a consequence, the directional control is difficult, drill string vibrations are a challenge for drill string integrity and down hole electronics, and drilling a side-track is far from easy. Finally, the stiff bottom hole assemblies have tight annuli giving enhanced circulation pressures, bore hole wall erosion and friction.
Steel shot drilling removes rock by exposing the hole bottom to a high pressure jet containing steel shot particles, see Figure 1. It requires minimal weight on the bit - just contact between bit and hole bottom - and uses conventional flow rates that ensures good solids transport and well control and drills through any rock type. Ideal for drilling large multilateral reservoir structures, even if the reservoir has limited thickness.

Figure 1 The spherical steel shot particles - diameter 0.6 to 1.2 mm. Picture by Tessa Veldhorst De Schaapjesfabriek©.

Steel shot drilling also had to overcome three major challenges:

1. Circulation of the steel shot particles is a burden for the drilling mud and the circulation system. This has been demonstrated by Gulf (Fair 1981) and resolved by the Shell down hole steel shot recirculation system. The Shell development has only been reported in a series of 16 patents starting with Blangé (2000).
2. Reduced bore hole wall quality – a complication for directional control and bore hole re-entry. This has been resolved by the Shell jet-bit design and the Canopus hybrid PDC-jet-bit solution, see Figure 2.

Figure 2 Holes drilled in limestone with a steel shot jet bit. On the right hand side a model of the drill bit including the down hole recirculation device as invented by Shell. Note the high bore hole wall quality. Picture by Tessa Veldhorst De Schaapjesfabriek©.

3. Directional control. Conventional solutions for directional control like rotary steerable systems and mud motors cannot be applied. This has been resolved by the Canopus steering through the steel shot concentration modulation method.

The Canopus DSSD technology has the following components:

- The steel shot jet bit, see Figure 3, or a PDC bit modified for PDC and Steel Shot jet drilling.

Figure 3 Prototype 2.9 inch steel shot jet bit and drilled holes in Belgian limestone. Picture by Tessa Veldhorst De Schaapjesfabriek©.

- The steering sub – discussed below.
- The surface system including the Steel Shot Injection system downstream the high-pressure mud pump, see Figure 4, and the steel shot retrieval system that separates the steel shot particles from the cuttings and transports them back to the Injection system.

Figure 4 Steel shot injection system. The two vessels inject steel shot alternatingly to facilitate continuous injection.

2.1.2 Fundamentals of steel shot drilling

Steel shot drilling removes rock by jet erosion with a steel shot laden fluid jet. The technique is similar to abrasive jet machining which uses edgy garnet sand to cut any material including steel with very high precision. For drilling brittle material like rock with a closed loop circulation system shot abrasives are preferred over garnet sand. An extensive field trial campaign on abrasive jet drilling was done by Gulf R&D in 1964 to 1973 (Fair 1981) demonstrating high penetration rates in many rock types and the dependence on bit hydraulics and abrasive particle concentration.

As a rule of thumb, the rock removal rate is proportional to the kinetic energy in all the steel shot particles impacting the rock face. Therefore, for a constant density of the carrier fluid, rock type, particle shape, diameter and particle density, the rock removal rate is proportional to the flow rate, Q, the bit pressure drop Pb and the volumetric particle concentration Cs. For further information on the physics of Abrasive Jet Machining see, for instance, Momber and Kovacevic (1998) and Zeng (1992).

As with conventional PDC or tri-cone bit, softer rock is drilled faster than hard rock and a similar inversely proportional dependence of Rate of Penetration, *ROP*, on the UCS of the rock applies.

One complicating factor is that soft and permeable rock and salt can be jetted away by the carrier drilling mud independent of the additional erosion by the steel shot. Compared to conventional mechanical drilling this effect is only stronger at the hole bottom underneath the bit, as the typical bit pressure drop for steel shot drilling is 150 to 500 bar whereas the normal bit pressure drop of for instance PDC-bits usually does not exceed 70 bar. As with conventional drilling, the flow rate for steel shot drilling is selected for getting good hole cleaning within the equivalent circulating density (ECD) window. As the need for drill collars in the bottom hole assembly (BHA) is reduced or even entirely absent, the risk of washing out the formation at the tight annulus around the BHA is reduced for steel shot drilling.

In soft rock a steel shot bit and a low concentration of steel shot are sufficient for a high rate of penetration. Another option is to use a PDC bit (with low weight on bit) modified for the combination with steel shot drilling.

The spherical steel shot particles do not damage the drill string or BHA-components as long as circulation velocities through the steel components do not exceed 10 m/s. This is consistent with general design rules for drill string components. If locally the circulation velocity would have to exceed the 10 m/s limit then specific measures, for instance ceramic lining, can be applied to increase that maximum velocity to at least 20 m/s. The tungsten carbide material for nozzles is extremely erosion resistant and can easily survive velocities of 250 m/s or more that are typical for the abrasive jet machining industry.

The selection criteria for the drilling mud are the same as for conventional drilling – stay within the ECD limitations and ensuring effective hole cleaning. The only additional criterion is that the mud rheology should have a yield point such that the low concentration of steel shot in the well does not sag (too much) during a circulation break during a drill pipe connection.

The ideal hole size for multilaterals in the reservoir seems to be 15 cm (6 inch). For example, at the same total production rate, two laterals of 15 cm and 500 m length each have a lower pressure drop than one 22 cm (8-1/2 inch) diameter horizontal of 1000 m length. The steel shot drilling assemblies are more flexible and easier to keep within a limited reservoir thickness.

The reduction or even absence of the weight on bit and torque on bit gives that drill string vibrations and shocks are expected to be reduced. This will have a positive impact on BHA longevity and the signal to noise ratio of down hole sensors.

Obviously, drilling more or longer laterals for limited additional cost would increase the chance of accessing good reservoir and would reduce the risk of disappointing productivity.

A final comment concerns the completion. As the laterals drilled with steel shot drilling are to be placed entirely inside the reservoir, there is less need for a completion. However, if there is a risk of bore hole instability a completion should be run. Of course, the drilled curvature should be consistent with the stiffness of the completion string.

2.1.3 Directional control of Steel Shot Drilling

The Canopus Directional Steel Shot Drilling (DSSD) technology is effectively a Rotary Steerable system. Steering the drill bit while rotating the string is advantageous for three reasons:

1. A rotating string improves hole cleaning
2. A rotating string can be pushed further into a horizontal and provides better control of the weight on bit.
3. Steering while rotating creates smoother trajectory with less friction.

Of course, life would have been easy if commercial solutions like rotary steerable systems or mud motor-bent sub could have been combined with steel shot drilling. Unfortunately mud motors are not compatible with a bit pressure drop exceeding 100 bar, and rotary steerable systems are complex and expensive and steer by pushing or pointing the bit. Pushing the bit is only effective if the bit drills by means of a mechanical contact force, and pointing the bit also has its limitations. For further general information on commercial directional drilling systems see for instance https://en.wikipedia.org/wiki/Rotary_steerable_system

The Canopus' steering uses the abrasive jet erosion itself for the steering action. As discussed previously, the rock removal rate is determine by the bit pressure drop, the flow rate and the steel shot concentration in the eroding jet. The jet bit has a single jet scanning the hole bottom while rotating together with the drill string. The bit changes its drilling direction in the case the erosivity of the jet changes while rotating the bit. Eroding more rock on one side of the hole bottom than on the other side changes the drilling direction. Figure 5 shows a steel shot drilled S-curve in Belgian limestone. The deviation was created by the differential erosion of the hole bottom as described above.

Figure 5 A 4-1/8 inch diameter borehole in Belgian limestone. The hole was drilled with a steel shot jet bit, and steered by erosion based differential hole making

The Canopus steering sub creates this so-called differential hole making by controlling the steel shot concentration and their time of arrival at the bit. The high inertia of the steel shot particles is used to direct the particles into a slow or fast fluid channel.

A low pressure 3D-printed mock-up has been developed with which this base functionality has been tested. The particle transport velocities in the two channels are chosen in such a way that the particles directed into the fast channel overtake the particles that entered the slow channel a moment earlier. This way, the two clouds of particles in the two channels reach the exit at the same time recombining to a higher concentration particle cloud, whereas a moment later the fluid through the two channels recombine to a liquid with low particle content.

As the steering sub is positioned only a short distance upstream the drill bit and the tool face and desired drilling direction are known, a control unit synchronizes the steel shot pulses with the rotation of the bit such that a high concentration reaches

the bit when the steering action requires more erosion and only a low concentration when that is required.
Figure 6 shows the signals of the particle concentration sensors in the fast channel of a prototype steering sub. The control of the actuator and precision of the concentration sensors is such that the shape of the steel shot concentration variation is rather precise.

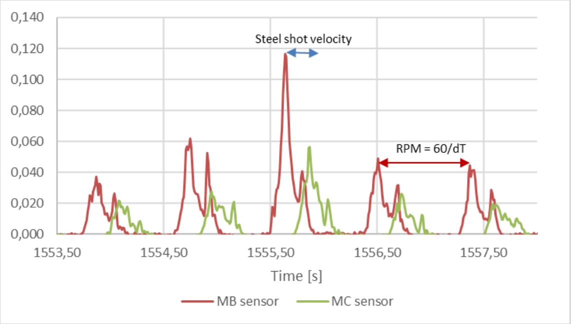

Figure 6 Two sensor displaced about 1 m along a tube detect the internal transport of clouds of steel shot particles. The time delay between corresponding MB (red) and MC (green) signals relate to the cloud velocity.

Even better: the control is such that not only direction of the erosive steering action is regulated, but also its amplitude. The latter is important for balancing the forward tangent hole making with the differential hole making and hence the strength of the steering action. This provides a means to control the sharpness of the turns – the dog leg severity.

2.1.4 Operational considerations

The operation of the steel shot drilling in the field will require setting up the rig interface and a few changes in the operational practices compared to the lab setting. A number of things do not change.

1. Directional control will be done by the down hole steering sub. Telemetry could be used to inform the sub that a different directional objective is to be pursued.
2. A pulser can still be used, but the design should be reviewed for compatibility with the 0.6 to 1.2 mm steel shot particles. This is to be verified in the piloting phase in the field.
3. The presence of the steel shot does impact the functionality of an MWD. The detection of the azimuth angle is not affected when bringing the typically ferromagnetic steel shot particles close to the sensors. This has been checked at RCSG with a commercial directional module, see Figure 7.

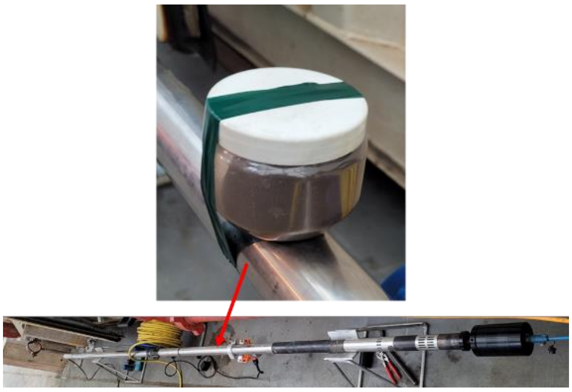

Figure 7 Cup filled with steel shot did not disturb the magnetometer signal in the Directional Module.

4. The volume of the steel shot particles in the well should be monitored closely. It is important to do proper bookkeeping of the volume injected and retrieved and model the expected location of the particles continuously. In the case insufficient hole cleaning is suspected the pressure response of a flow rate change can be used to diagnose.
5. Flow rate is determined by ECD and hole cleaning considerations as in a conventional operation.
6. Well control is to be done as in a conventional drilling operation.
7. As the drill string gets longer with depth, the pressure required for mud circulation increases similar to conventional operations.
8. The bore hole wall is smooth and the particles are not lost in softer rock. Only when the bit is in front of a vault and mud losses occur steel shot particles will go together with the lost mud.
9. Most topdrives have a pressure rating that limit the full potential of the directional steel shot drilling. Top drives can be upgraded by mounting a false high-pressure shaft inside.
10. The steel shot injection system is mounted in a bypass of the mud circulation line. If necessary the injection system can be isolated from the mud circulation system within seconds.
11. The steel shot injection system is an alternating dual vessel system providing continuous supply of steel shot particles. RCSG has an operational continuous steel shot injection system.
12. Steel shot drilling produces fines, but also a small amount of cuttings up to 3 mm. These can be analysed by the geologist on site.
13. The performance of the steel shot drilling can be monitored from surface by detection the pump pressure response to steel shot particles passing the bit nozzle. At a 0.5%vol steel shot concentration the density of the mud increases by 3.5%, which changes a bit pressure drop of 300 bar with 10 bar. Variations like this on a few-seconds scale are clearly reflected by the pump pressure at surface. As the steering sub controls that concentration the system implicitly includes a mud pulse telemetry solution.
14. Drill tests have been performed in concrete, shale, granite, hard limestone, and sandstone. Longevity is expected to be determined by the pressure and particle exposure and not by the target rock type. Actual longevity in field conditions is to be verified in the follow-up piloting phase, but longevity of an assembly is expected to easily exceed 100 hrs of down hole operation.
15. The temperature range of the down hole electronics limit the operating range to max 200˚C.
16. The use of hybrid hole making including both PDC drilling and steel shot drilling is very interesting. The abundance of hydraulics at the bit face and the erosion of a large part of the hole bottom by the steel shot jet seem to reduce the hold down effect that typically reduces the PDC cutting efficiency

with depth. As cutting produced by the steel shot jet are small the hold down effect is of limited importance to the jet erosion.

17. In the case of combined PDC drilling and steel shot jet drilling a combined drill-off test should be done to balance the mechanical drilling action based on *WOB*RPM* with the steel shot drilling action based on *Q*Pb*Cs*. Of course the PDC action should not lead to mechanical loads that undermine the advantage of use the steel shot drilling with virtually zero WOB.

2.2 Scope of research

The goal of the executed project was to mature and demonstrate, under actual downhole hydrostatic conditions at the RSCG, a novel directional abrasive drilling technology which enables the drilling of long horizontal wells from a vertical well through the reservoir. This technology is based on directional abrasive drilling with down hole re-use of abrasives which could contribute significantly to the cost-effective drilling of geothermal wells. The project delivered experimental results of a full-scale prototype with steering capabilities for optimized well trajectory control of abrasive drilling for horizontal wells. A plan to initiate pilot projects was delivered as part of this project.

2.3 Method

This project aimed to mature and demonstrate a new directional drilling technology under actual downhole hydrostatic conditions at the RSCG. The technology is based on directional abrasive drilling with down hole re-use of abrasives. A scoping in WP 1 investigated the system and compared it to alternatives. The first step to get to a fully operational system was the investigation of the (magnetic) control of the concentration and transport of the abrasives in the cutting flow loop (WP2). Secondly, the existing 50T hydrostatic drill test facility was prepared and tested (WP3). In WP4 a directional abrasive steering sub prototype was hydraulically mounted downstream of the abrasives injection system and an electronic interface was built. The actual directional testing took place in WP 5, comprising the testing of the steering sub functionality and the directional response of the drill bit inside the pressure vessel on rock samples (cement, sandstones, carbonates). WP 6 evaluated the potential for field application and drew up a plan for field tests on potential field test locations in Europe. Work Package 7 was dedicated to the overall reporting.

The project delivered experimental results of a full-scale prototype with steering capabilities for optimized well trajectory control of abrasive drilling for horizontal wells. A plan to initiate pilot projects was delivered as part of this project. A consortium of partners contributed to defining how the system should work under pilot conditions and followed the results of the experiments to understand the technology and understand the advantages that can be gained in a full-scale implementation in the field. It is critical that the steering capabilities directional drilling technology match the field requirements of the future geothermal operators.

2.4 Results and conclusions

The aim of the first work package was to understand how directional steel shot drilling of multi-laterals can enhance geothermal development and how the technology compares to other techniques to enhance flow from (geothermal) wells. In the report the importance of Canopus Directional Steel Shot technology is explained to drill multilaterals for the future development of geothermal energy and therefore the need for the technology that enables horizontal drilling. It includes a brief discussion of the need for boosting production per well and scope for existing well performance enhancement options and their production. The second part of the report investigates the value of the steel shot drilling compared to other drilling enhancement technologies. It includes comparison with novel, and conventional drilling technologies. Finally, an overview is given of the investigations that are needed to increase the Technical Readiness Level (TRL) to the point where it can be applied in pilot and field demonstrations. These investigations focussed on operational issues on hydraulics and wellbore cleaning, and base system investigation of directional control and robustness of the steering sub.

The experimental work of the second work package was looking into some specific issues of the proposed abrasive jetting drilling technology. This novel directional drilling technology is based on the ability to transform a continuous supply of steel shots into a controlled fluctuating concentration while eroding a rock ahead of the bit. The key component of a successful application is the ability to transport both the steel shots and the cuttings, in particular in the horizontal leg of the well, because the drilling string can get stuck when the removal of cuttings is not properly done. An experimental investigation has been undertaken for the particle transport, hole cleaning requirements, and steering concept at a dedicated flow loop in TNO’s Rijswijk Centre for Sustainable Geo-Energy (RCSG). The results of these experiments enable the definition of the Equivalent Circulating Density (ECD) and the impact of transient effects on the ECD. This will determine the optimal hole cleaning while drilling multilaterals and the maximum length the technology can drill while staying within the safe ECD margin. The reported outcomes of the experimental study focus on the capabilities of the experimental setup to validate hole cleaning and annular pressure drop equations. These capabilities are demonstrated by the executed tests divided into three phases; 1) the impact of steel shot transport on the hole cleaning and the ECD in an annular configuration, 2) the impact of realistic operational conditions, such as (ec)centricity and pipe rotation, rheology, abrasives type and concentration and addition of drilled cuttings on the solids transport in the horizontal section, and 3) the transformation of a continuous supply of steel shot particles into a well-controlled fluctuating concentration. The value of experimental research on the flow loop was demonstrated by valuable results that proved to be sufficient for modeling the conditions for hole cleaning to estimate the reach of long laterals and to prove the steering concept. Mimicking the complex drilling conditions for testing hydraulic requirements during the drilling has significantly derisked the performance of the tool bringing the technology to a higher Technical Readiness Level (TRL) level. Whereas the investigation focused on the particular aspects of the steel shot drilling, the experimental set-up, and the results can be applied more generic for other types of horizontal drilling.

Activities of the last three workpackages revolved around the testing of the technology under relevant subsurface conditions that can be mimicked in the so-called 50T drilling set-up. The main application of the 50T drilling machine is to test the performance of drilling technologies on different rock specimens under downhole pressure conditions, with varying mud properties and drilling parameters. The mechanical back-bone of the machine is formed by the platform on four legs and a base construction anchored to the floor. The actual drilling process takes place in the so-called “bombe”, a pressure vessel that can sustain pressures up to 250 bar, and houses the rock specimens to be drilled. The activities involved the preparation of the equipment and the integration of the steel shot subsystems. Phase one was dedicated to the operational preparation of the 50T drilling system and training of the staff. The phase was completed with the first successful drilling test to confirm

operability and functionality of the machine. In the second phase fully operational steel shot injection unit was connected to the 50 T drilling machine, whereas functionality of the system was tested by conducting a series of drilling tests in concrete and granite rock samples. In the final phase the Canopus steering sub was installed as the last part of system integration and further tests were undertaken.
The conducted drilling tests showcased the functionality of the steel shot injection unit and the control over the injection parameters and small deviations were observed in the drilling path. The connected Directional Module with Steering sub control unit showed that the interface and the principles behind the tool worked. The jetting action was more than sufficient for the steering. There seems to be an ROP increase resulting from the combination of PDC and SS jet drilling. Further work is needed to finalize the pulse detection at the bit, but major steps were taken in the maturation of the technology.

In the last Work Package, the potential for production increase resulting from horizontal and multi-lateral wells was investigated for three very different reservoir types:

- Homogeneous porous sandstone reservoirs such as might be typically found in The Netherlands.
    - For the homogeneous, sandstone reservoir in The Netherlands, three Canopus laterals of 1000 m for the producer as well as the injector delivered 2.4 times the geothermal power of a conventional doublet
- A fractured reservoir with very high heterogeneity and uncertainty in Schlattingen, Switzerland.
    - The simulated increase for the three Canopus laterals depended strongly on the assumed heterogeneous fracture distribution. On average, a horizontal well instead of a vertical resulted in an increase factor of 2.6 and three laterals in an increase of 2.8, but the range is large.
- A strongly layered, thin limestone reservoir in the Paris Basin.
    - Similar increases were simulated in productivity/injectivity for the most optimistic case as in the Netherlands

These studies focused on the potential increase in productivity assuming the abrasive jet drilling technology is able to drill the used geometry. In addition for several (potential) geothermal reservoirs in Germany, a study was done assessing whether abrasive jetting would be feasible from a geomechanical perspective. For most of the potential geothermal reservoirs, abrasive jet drilling appeared feasible. For some systems (Buntsandstein and Upper Muschelkalk in Upper Rhine Graben), the amount of information was insufficient in particular due to a lack of pore pressure estimates.

2.5 Description of the contribution of the project towards the goals of the subsidy program (sustainable energy system, strengthening knowledge position)

Geothermal energy is considered as one of the most important future contributors of sustainable (fossil fuel free) heat in the Netherlands for heating of the built environment[1]. The demands for heat constitute about 40% of the emission in the Netherlands. Emission reduction targets demand that the CO_2-eq emission from heat generation needs to be cut 20 megaton before 2030 and an additional 36 megaton before 2050 . Large-scale implementation of geothermal energy could result in a 3 megaton decrease in 2030 and 12 megaton decrease in 2050. Geothermal energy can grow as source of heat from 0,5% of the total heat production to 5% in 2030 and 23% in 2050. The number of geothermal doublets in the Netherlands will have to grow from the current 24 to about 175 in 2030, and subsequently to 700 in 2050 to

---

[1] Masterplan Aardwarmte in Nederland, een brede basis voor een duurzame warmtevoorziening, 2018.

reach these goals of the geothermal sector[1]. These wells cannot be drilled and operated at the same costs (€ per GJ) as are common at the moment for typical geothermal wells, because the current subsidy scheme that is required to make the pay-back time for these wells acceptable cannot be sustained. New concepts or technology is required to support the growth of the geothermal energy sector. The abrasive jetting drilling technology that is tested and developed in this project has the potential to deliver the required cost reductions (€ per GJ) for this expected growth. The impact on the Dutch market for heat of the widescale application of this technique could be, given the number of wells to be drilled as stated above, very significant as it might help the keep the costs for household and building heating low and affordable. Horizontal drilling from a vertical well also helps to limit the surface footprint of the geothermal industry, thereby making it socially acceptable.

This project enabled the Rijswijk Centre for Geo-energy to make, from a global perspective, unique research equipment and infrastructure available for open innovation. Equipment and infrastructure that until very recently was reserved for the oil and gas industry is now be available in support of the energy transition in the Netherlands and internationally. This helps to position the Netherlands as a champion in the development of low enthalpy geothermal systems, which will surely lead to export of knowledge and products to international markets.

In conclusion, the results of this project will help the developers of geothermal doublets in finding ways to reduce costs of geothermal projects. The society as a whole benefits from reduced costs on projects as it supports the existence of an affordable heat source. by lowering the costs in order to keep the delivery of heat affordable.

2.6 Follow-up, spin off inside and outside the sector

Within the DEPLOI project some major steps have been made to mature the technology and significant progress has been realised towards field application. In the context of a generic maturation sequence as defined by the Technical Readiness Levels (TRL) levels (Figure 8), the DEPLOI project has demonstrated the technology in the lab (TRL 4) and has tested it in the 50T drilling set-up, which is creating a relevant environment as it mimics the actual drilling conditions. The technology was in the early stages of TRL level 5 after the project (mid 2022). The next challenge for the technology development is the maturation from TRL 5 to 7 where the technology is tested in the field. A new project should deliver this development.

At the end of 2021 there has been an opportunity to send in a proposal for the GEOTHERMICA call. GEOTHERMICA's objective is to promote research and innovation in geothermal energy to make geothermal energy reliable, safe and cost-competitive[2].

The GEOTHERMICA call that was launched in 2021 was identified as an opportunity to develop the technology towards the next TRL levels and a specific proposal has been set-up. The goal of this project will be to demonstrate the prototype in the test environment at RCSG (in the 50T drilling equipment and in the available well) to bring the technology to TRL level 6 and to test the technology in pilot projects in the field (TRL 7).

---

[2] http://www.geothermica.eu/about-geothermica/

1. Basic principles observed
2. Technology concept formulated
3. Experimental proof of concept
4. Technology validated in lab, implementation and test of prototype
5. Technology validated in relevant environment, validation of prototype
6. System prototype demonstration in test environment
7. System prototype demonstration in operational environment
8. System complete and qualified
9. Actual system proven in operational environment, market introduction

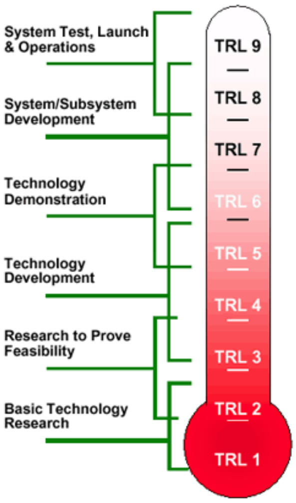

Figure 8 Technical Readiness Levels (TRL) levels

The two field trials (2023-2024) in the proposal are to demonstrate that capability in two typical environments with increasing operational complexity:

- the drilling of a multilateral construction in tight limestone at the VersuchsStollen Hagerbach in Switzerland at surface;
- a deep geothermal district heating project in a typical Dutch hot water sandstone reservoir in Ede, The Netherlands.

Both trials are supported by thorough field equipment testing at the Rijswijk Center of Sustainable Geo-energy of TNO, drilling system modelling and real time monitoring by the center of excellence on well construction at the University of Calgary and the extensive operational expertise on directional drilling for Geothermal of Well Guidance. As such, it would be a direct spin-off of the DEPLOI project.

The secretariat of TNO's research group Applied Geosciences can be contacted for further information regarding this project via via secretariaat-aarde@tno.nl.

The project has been carried out with a subsidy from the Dutch Ministry of Economic Affairs and Climate, National Schemes EZ-subsidies, Top Sector Energy and carried out by RVO (Rijksdienst voor Ondernemend Nederland) and was further supported by (in-kind and cash) contributions from consortium partners.