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From Gas to Geothermal, an Overview from the Netherlands

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ABSTRACT

The Netherlands is a densely populated country known for its flat countryside of which a large part is located below sea-level. The geological formations are formed by alternating sea, river, desert and wind deposits over millions of years what resulted in an abundance of hydrocarbons in the subsoil and over 5000 drilled oil and gas wells. Until recently, gas has been for decades the standard heat source for houses and industry. Now, geothermal energy is considered a logical part of the energy transition in The Netherlands thanks to the available knowledge of drilling and the subsurface. The Netherlands is a global player in growing fruit and vegetables in greenhouses. Greenhouses are high tech production facilities that increase the harvest yield and reduce the usage of water and energy. Greenhouses account for about 5% of the gas consumption in the Netherlands to grow vegetables all year long. As early adopters, low enthalpy geothermal energy is increasingly used in The Netherlands by greenhouse owners despite the relatively low thermal gradient and availability of gas. The significant baseload heat demand of the greenhouses in combination with the knowledge of the subsurface and drilling were the enablers of geothermal energy although costs and risks remain serious threats. Compared to the oil and gas industry, geothermal drilling is often less efficient due to a number of structural differences. Therefore, the reduction of drilling cost and the resulting cost per produced MWth is crucial and does require the geothermal industry to take initiative. Drilling wells capable of producing larger flowrates seems a logical solution, and this results in more geological and drilling risks and associated cost. Currently, over 130km of geothermal wells have been drilled in The Netherlands; hence, sufficient information data is available to review. An analysis of the encountered problems and solutions of systems in the different geothermal regions will be presented. The impact of using a drilling campaign (portfolio-based) approach as executed in 2018 by Well Engineering Partners for a major greenhouse consortium in The Netherlands will be presented. Drilling campaigns are a common practice for oil and gas operators. The geothermal case study has been completed approximately 1 million Euro per well under budget with zero incidents. Finally, this resulted in a cost reduction of 24%. Also, another drilling campaign of a triplet in 2018 resulted in a significant cost reduction, namely 15%. Besides the described analysis, opportunities to reduce cost and risk will be presented which are required to define the next generation greenhouse geothermal wells and drilling practice. The learnings from these early adaptors are essential to use geothermal heat for city heating in the Netherlands. Outside the Netherlands, the proven combination of geothermal energy and greenhouses may bring value as a highly efficient, local, controlled, and sustainable food production facility.

INTRODUCTION

The discovery of the Groningen gas field in the 50's enabled the Netherlands to move from coal as an energy source to cleaner and practical heat source of natural gas. The construction of a national gas net made it possible to upscale the production and efficiently distribute the output. This gas net resulted in cleaner and cheaper energy to supply the total population and industry in the Netherlands and beyond. The increasing and fluctuating global oil and the linked gas prices in the first decennia of the 21st century affected the business of many gas-intensive and dependent companies such as the many large greenhouses in the Netherlands that use heat but also CO2 from gas. Although the first commercial geothermal system in the Netherlands used abandoned mine shafts as a reservoir for residential heating, the purpose of the most following systems was for greenhouse heating. The available subsurface knowledge and experience from the oil & gas industry in the Westland/Oostland region near Rotterdam in combination with the many greenhouse entrepreneurs resulted in 10 geothermal plants in the Westland/Oostland area. The current greenhouses show that geothermal heating is a cost-effective alternative for gas. Thanks to the locally sourced heat, local heat nets, high heat demand and good heat match between subsurface and heat net. The Dutch state supported the geothermal industry with a production insurance scheme and a production-based subsidy scheme. Some of the owners of geothermal plants started to sell heat to neighboring communities and greenhouses by expanding their heat net and plants. CO2 from other industries transported via pipelines are used to replace the CO2 from gas.

More recently, the decision from the Dutch government to stop the production of gas from the Groningen gas field in combination with the required energy transition increased the interest in geothermal energy. Studies confirm that geothermal energy offers a very cost-effective solution to reduce CO2 emissions for greenhouses, but the total potential is limited on a national scale.

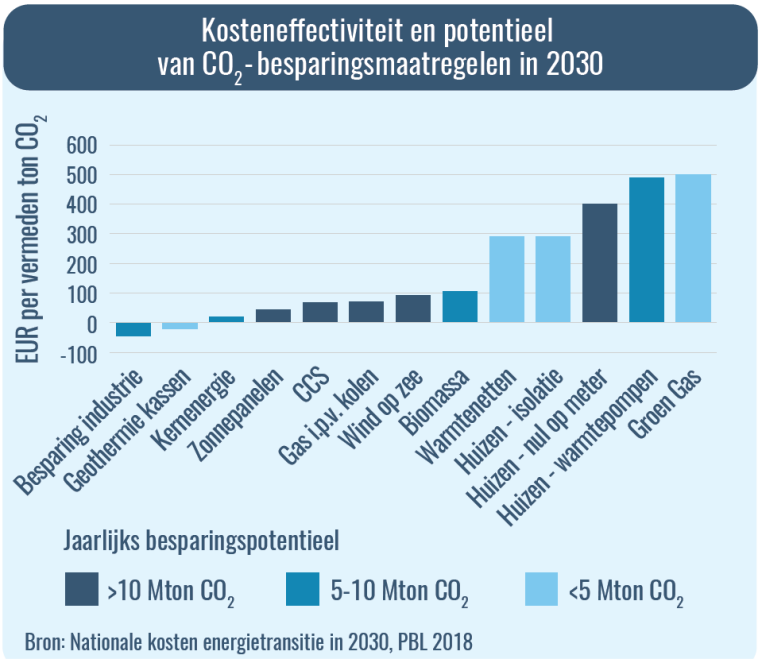


Figure 1. Source EBN infographic 2019.

A few issues will need to be tackled to make geothermal energy a relevant option in the future energy mix for residential heating, industrial applications, or electricity generation in a cost-effective manner. Geothermal district heating has the least uncertainties but already demonstrates the issues below to be resolved:

1) Typically the gas & oil fields don't overlay with the large residential areas; this implies that the subsurface knowledge doesn't match the heat demand. Therefore the knowledge of formations below the large residential areas will need to be improved what may require exploration drilling. The potential to repeatability needs to be large enough to justify an exploration well.
2) Thanks to the abundance of natural gas is there a widespread gas net in the Netherlands, but the number of heat nets is limited. The construction of heat nets, especially in a residential area is expensive and time-consuming.
3) A temperature mismatch between what the earth has to offer and the heat net needs is solvable, for example with heat pumps. However, this will lower the total systems efficiency and make the heat more expensive.
4) Safety and reliability during both construction and production phase are essential elements to ensure and maintain public acceptance.

The issues mentioned above will eventually all have a negative impact on the cost of heat hence a cost reduction in terms of euro per MWth will need to be made during the realization of geothermal systems. To improve the cost per MWth ratio for a given formation either the drilling costs are reduced or the operating cost. The temperature is given fact. A larger production rate will increase the drilling costs (larger well) and/or increase operating cost (higher pressure drop means more pump electricity used and risk for erosion issues). Reducing drilling cost has always been a theme in the global oil & gas industry and it is crucial to make geothermal energy a success.

WELL CONSTRUCTION ELEMENTS

Drilling a well is done following a multi-disciplinary process that includes task assigning heat contracts, organizing finances, acquiring permits and lands, and designing the geothermal system. The subsurface part of the system is a significant part of the total expenditure, and additionally, the realization and commissioning come with significant risks. Therefore, a structured well engineering process is to be used to ensure that the most fit-for-purpose well is constructed at the lowest possible risks. The procurement phase in which the most suited companies are identified to deliver the various services, equipment, and materials is essential and often very time consuming. Usually, the drilling rig covers the most significant share, as shown in the overview below. It indicates as well that a large number of services etc. are required that are often delivered by different providers. The procurement objective to find the cheapest provider possible is, therefore, challenging as one service impacts the performance of the other. E.g. drilling fluid specifications may cause directional tools not to work or even to fail. Many service providers operate also for the oil & gas industry; hence, their price level depends on oil& gas drilling activity. The same applies to the materials used to build the well. Furthermore, the exact formation properties drilled through cannot be known in advance what results in uncertainties such as formation depths and the precise amount of casing required. These risks often result in the second largest cost item: the contingency & probability line.

Location preparation	**13%**
Construction of location & installation of conductor	13%
Drilling Services	**23%**
Drilling Rig	23%
Locations and Other Services	**32%**
Directional Drilling services	6%
Wireline Logging	2%
Drilling Fluids	7%
Cuttings handling & waste disposal	5%
Cementing services	3%
Mud logging	2%
Crane + Transport services	1%
Wellhead Installation	0%
Tubular running services	1%
Other services/items	1%
Well Testing Services	4%
Consumables	**28%**
Casing	2%
Casing	6%
Wellhead	1%
Fuel	4%
Screens	0%
Liner Hangers & cement equipment	3%
Others	0%
ESP	11%
Supervisory & engineering	**3%**
Drilling management	3%
Total	**100%**
Contingency + probability percentage	*15%*

Another high cost, especially for geothermal drilling in an urban environment, is the location. In the example, only the construction of the location, including installation of the conductors is taken into account, but purchasing land will have a significant impact on the business case.

DAYRATE VS. TURN KEY DRILLING

Well Engineering Partners has been involved in almost all geothermal drilling in the Netherlands. 46 geothermal wells have been analyzed, that are drilled from 2006 to 2018. As absolute well costs are influenced by market conditions, that have significantly varied over this timeframe a comparison has been made based on time. For the evaluation, the time from spud (start of drilling first section) up to the installation of the lower completion in the reservoir section. As these geothermal wells have a similar well profile and design, this has resulted in reasonable comparison of performance between wells.

A significant difference has been seen in performance between wells drilled 70 days vs. 40 days respectively under a day rate structure, managed by a drilling operations team of the Operator, and a lumpsum structure, led by the Contractor. With a large part of cost being time dependent (e.g. people on the rig) the lumpsum option will be more expensive on average.

The lumpsum drilling was in particular popular for the early projects, but more recent the day rate drilling option has become more used. The choice between the two options is mainly driven by cost vs. financing requirements where financers are willing to pay to reduce risks. On the other hand, the public database with well data of all wells drilled in the Netherlands makes it possible to determine fairly accurate the drilling risks in advance what can be a useful tool to scale up drilling activity.

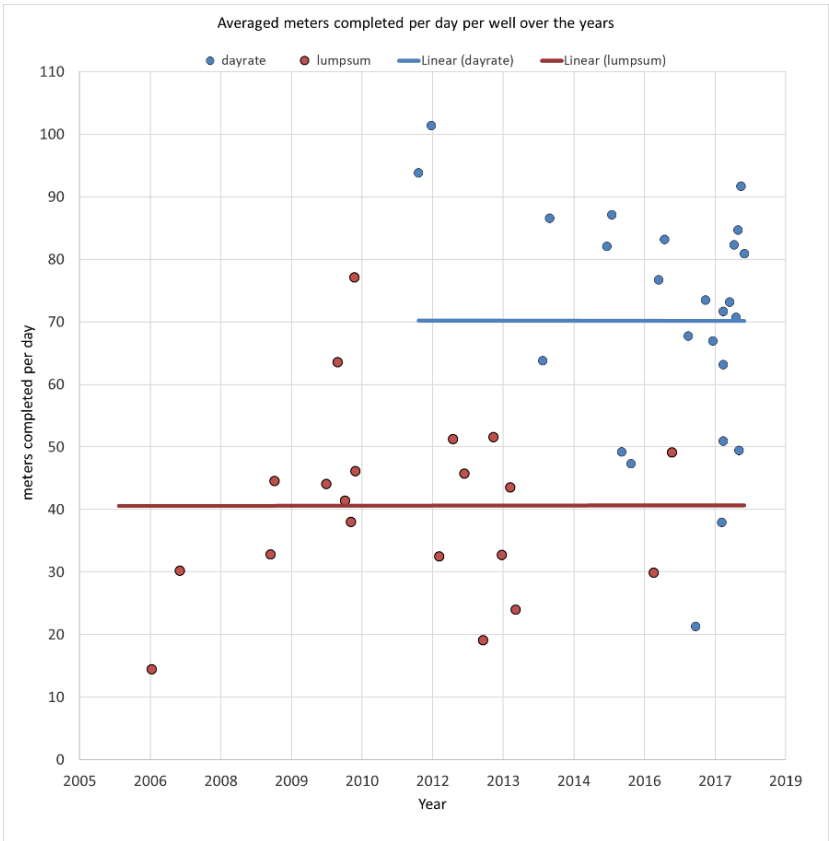


Figure 2. Footage comparison dayrate drilling vs. lumpsum drilling: Dayrate drilling is more productive per day.

BENEFITS OF DRILLING CAMPAIGNS

The Dutch state institute TNO and state-owned company EBN described the benefits of a play-based portfolio approach especially in terms of value of information that is required to develop geothermal energy as a well-accepted method from the oil & gas industry to developed certain reservoirs. Known from the oil and gas industry is that drilling campaigns, i.e. the drilling of multiple wells in one continuous sequence, will bring significant cost benefits.

Projects are one-off events that, even though they may resemble each other, each has their preconditions. This one-off approach is in contrast to ongoing processes in which the same action or activity is performed many times in succession. By streamlining the various actions, an optimized process can be carried out as efficiently as possible. Because of the differences between multiple standalone identical projects, this is somewhat more difficult there. This also applies specifically, to the drilling execution phase. However, by portfolio approach and standardizing between the various (parts of) a project, optimization can also be realized. The following issues are primarily crucial for standardizing drilling projects.

- Execution of projects in a contiguous series
  - Learning curve
- Uniform choice of materials
  - Standardization
- Same suppliers involved
  - Purchasing advantage
- Introduction of novel drilling solutions
  - Spreading risks in smaller steps

Execution of projects in series

Geothermal drilling projects are usually executed in short series of two wells: An injector well and a producer well. In a conventional geothermal project, the second well is often drilled more efficiently than the first. Because the second well includes improvements from the first well. This concerns both technical (as described below under "suppliers") and geological. This knowledge is used freshly by carrying out projects in series. The written finesse of such experience is often lost in written reports; especially when it comes to (apparently) small points.

In extensive drilling projects for oil and/or gas at one location, batch drilling is sometimes used for this. Multiple wells are drilled at the same time, while the different hole sections per well are drilled in turns. This means there is as little time as possible to let the experience sink. An additional advantage of batch drilling is the simpler logistics; only one type of tool, mud, casing etc. needs to be supplied per section.

Continuity of services
Although the various tasks on different projects are very similar, there will always be (small) differences. For example, with the rig up or rig down of external services on the rig, such as casing running equipment or wireline measurements. Specific operations can also vary between rigs or suppliers (for example, creating BHA or liner hangers). By using the same suppliers on different projects, such, sometimes small, often specific improvements can be included throughout the various projects.

For this, it is not only important that the same company is involved, but also a certain continuity in staffing is preferred. This means that everyone involved is personally as familiar as possible with the various points for improvement.

Note that the operator may not necessarily be the same in a series. Also, this is common in the oil & gas industry where especially offshore rigs, including all services and contracts are shared between operators.

Because the team responds better to each other on different projects, less time will be lost due to miscommunication and hidden delays. This is also referred to as the "learning curve". This can save up to 10% of the expected project time. (approx. € 350,000 out of a € 5,000,000 drill hole)

Additional savings when drilling at the same location
In addition to all the above savings, further savings are possible by developing a larger number of wells from one and the same location. An additional "learning curve" plays a role here, because experiences with location-specific circumstances are also taken into account.

Besides, the additional costs for enlarging a location to place an extra well are limited compared to an entirely new location.

Preparation phase
During the preparation phase, a threefold increase in scale is beneficial in a six well project. With a doublet, location-specific preparations are already combined, such as

- HSE documentation,
- license applications,
- analyzes of nearby wells,
- geological surveys and
- (sharing) of well designs.

With an increased number of wells, such one-off costs will be distributed over a larger number of wells, making the cost per well lower. With a triple increased number of wells at one location, these benefits can amount to around € 100k per well. This will be less at different locations.

However, due to the aforementioned standardization of materials and suppliers, there is also a noticeable advantage in projects at different locations.

Scale advantage
The purchase volume increases by performing a more significant number of wells in a series. As a result, there is also an advantage of larger purchasing orders. This applies to both materials and services. By purchasing larger batches of materials, a supplier has to incur lower costs for marketing, planning, transport, etc.

For services, the advantage lies primarily in longer-term contracts and the associated reliability for suppliers. They can record their personnel and tools (e.g. rig, BHAs) for a longer period of time. The long term contract means that a smaller margin can be calculated to cover the uncertainty of the work.

For materials, the expected benefit is around 2% (approximately € 30,000 per well of about € 5,000,000). Also, cost related to required excess (e.g. casing) and back-up equipment can be reduced.

With services, this benefit can be expected to be even greater; around 8% on average. (approx. € 280,000 out of a € 5,000,000 drill hole)

Budgeting / risks
A base case is made for the time estimation of a well or doublet; this assumes an efficient operation in which all individual steps are carried out without delay. In order to get at a realistic estimate, "contingency" is added on top of this to cover operational inefficiencies and uncertainties in pricing (total around 10% for a doublet). Examples of this are variations in tripping and drilling speed.

In addition, a "probability cost" is included in the budget (a total of approximately 10% of the costs for a doublet). This is a function of the costs of possible events plus the estimated chance of the event. These are, for example, delays (including failure of drilling tools or machines) or problems in the wellbore (including borehole instability, an influx of reservoir fluid or gas).

Especially the chance of problems decreases when performing wells in series; partly thanks to the previously mentioned "learning curve".

In this way, the "probability" cost can be reduced in the budget for a larger series of wells. The contingency costs remain primarily the same ratio, but due to the reduction of the total costs, the absolute value thereof will also decrease.

For the probability costs, the expected benefit is approximately 25% (approximately € 125,000 on a bore of approx.. € 5,000,000. For the contingency costs, the expected benefit is 10% of the total savings resulting from the above (approx. 1.5% of the total costs).

The next total saving is expected to be approximately per well by drilling in a series of approximately three comparable projects (6 wells). The actual savings will depend on the total length of the series (number of drilling projects / wells) and the mutual differences between the individual wells but a saving of at least 15% on the total drilling budget can be expected. Some savings will be noticeable at the start (standardization, economies of scale). The continuity is only sufficiently noticeable throughout the whole drilling sequence.

Examples

Figure 3 shows the time and costs of three comparable geothermal wells, drilled from the same location and managed by Well Engineering Partners according a dayrate scheme. All 3 wells were finished but the figure clearly shows the relation between time and cost (i.e. time is money). The first well cost the most time and money (which also drew an unintended sidetrack) and that every subsequent well shows an improvement.

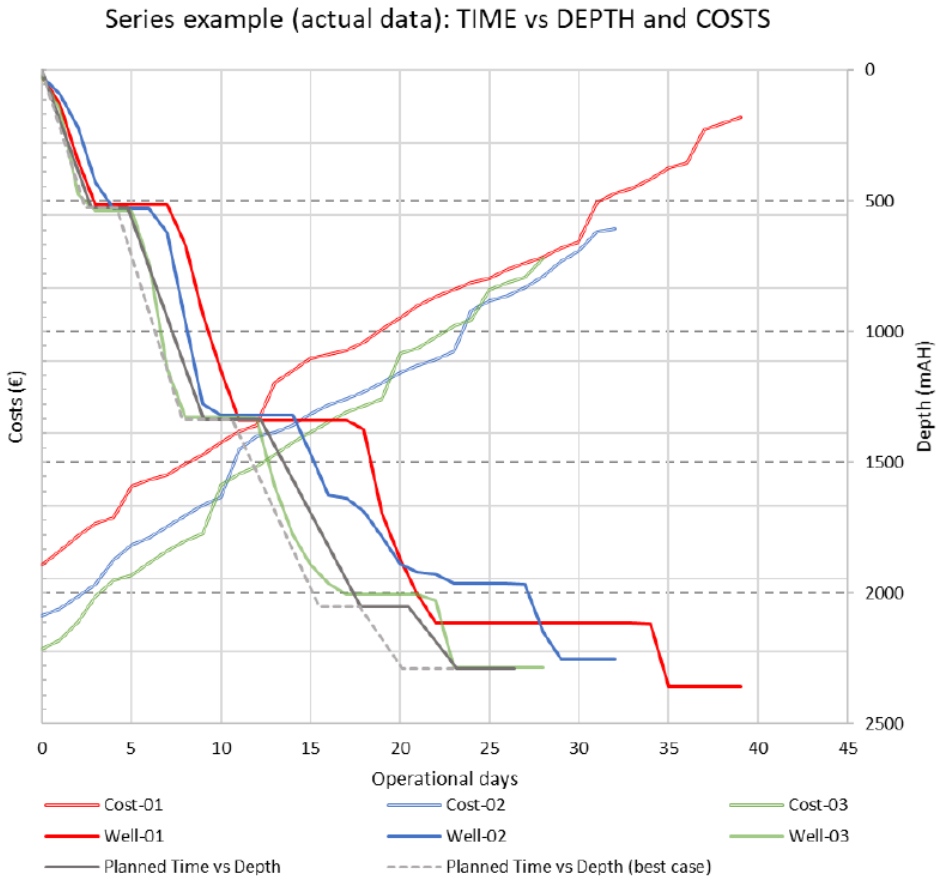


Figure 3. Overview of time-depth/cost curves of a series of 3 wells demonstrating the learning-curve effect.

Demonstrated financial gains during improvements of two of WEP's relative short drilling campaigns in The Netherlands are **15%** and even **24%** cost reduction in respectively a triplet (3 wells) geothermal project and 4 geothermal wells (2 doublets) project, respectively, see Figure 4 below. Both projects are low-enthalpy geothermal projects with its target in the Rotliegend sedimentary basin at approximately 2000m depth.

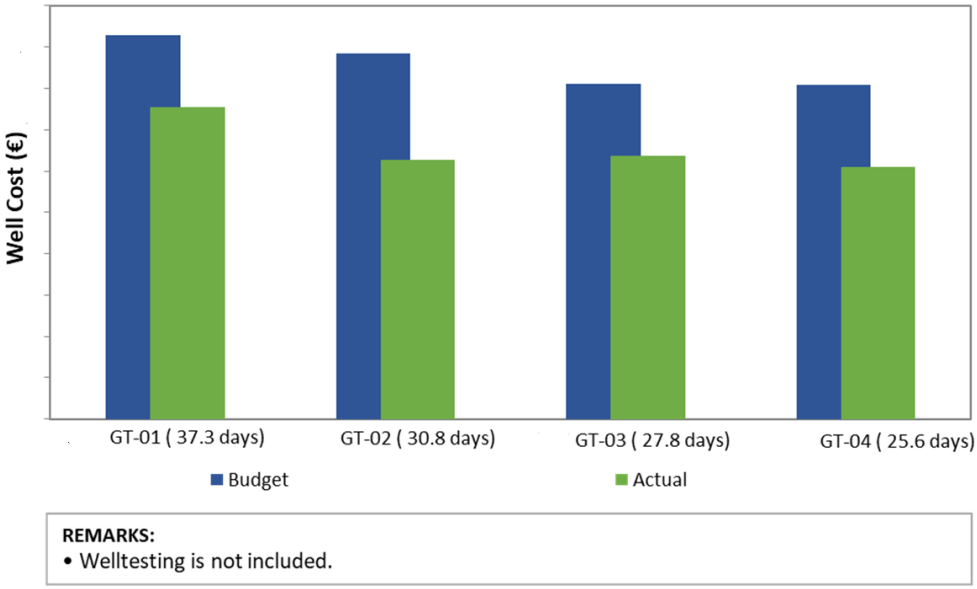


Figure 4. Budget vs Actual cost for drilling campaign project with 4 wells.

LIFE-CYCLE COST

The business case of a geothermal doublet is marginal when compared to oil and gas wells. Financing such projects proofed to be difficult for the greenhouse owners and therefore the initial CAPEX investments were restrained resulting in wells that were not designed for the lowest cost when looked at the complete well life. Especially in the last few years, companies with (geothermal) energy delivery as core business have become active and they focus more on total cost and the business case based on various wells rather than financing a single doublet. This change of business focus and the experienced problems in the aging wells impact the well designs. Also, the move from greenhouse heating to residential heating means a larger public involvement in geothermal energy. To secure the social acceptance the geothermal system will need to reliable, safe, and cost-effective. This is in-line with the objectives of the companies having (geothermal) heat delivery as their core business; hence, a next-generation geothermal well is needed for the next generation geothermal operator.

NEXT-GEN-GEOTHERMAL WELL FOR THE NEXT-GEN-GEOTHERMAL OPERATOR

The constant development of the geothermal industry lead mainly to larger well sizes and some different reservoir completion options with the main focus. Currently, WEP has initiated a next-generation geothermal well program that reviews the captured learnings from the wells delivered till date and anticipates on the increased focus on life-cycle-cost and reliability. A number of topics are being looked at to strengthen the geothermal industry.

Typical objectives and topics are:

- Improving life-cycle cost and reliability by investigation the options to reduce corrosion and erosion effects an example is the use of composite materials as tubing or casing
- Improving the efficiency of a geothermal system by investigating the artificial lift options and to optimise the well design accordingly. In the Netherlands all geothermal producer wells are equipped with an Electric Submersible Pump (ESP) installed on tubing and most problems in the wells relate to these ESP's either they fail or the high flow area around them cause erosion wear on the surrounding casing. Besides finding a way to improve the efficiency
- Lowering well construction cost and increasing reliability by investigating alternatives for sand control to geomechanically stability and number of casing string reductions

CONCLUSION

Similar as various decennia ago an energy transition is happening again in the Netherlands concerning the sub-surface. Learnings and knowledge acquired in the past from oil and gas exploration on areas as geology and drilling methodologies can be (re-)used. The sub-surface data helped to start-up the geothermal activities in the Netherlands but cost of drilling seemed to be a difficult hurdle to overcome to get robust business case and a reliable energy source.

Proven cost reducing methods as portfolio based drilling are difficult to achieve due to the differences between hydrocarbon and geothermal organizations although the first mini-campaigns have been drilled with good results. Estimates show that a cost reduction of over 15% are realistic when drilling a series of 6 wells (3 doublets).

Social acceptance and reliably, cost-effective wells are crucial to enable geothermal energy to be used for residential heating. This shift in focus is becoming visible and is driven by companies with a strong focus on geothermal energy as core business and well-life-cycle cost. Financing is becoming less of a hurdle while weakness in well designs are being repaired and innovative solutions are looked at to support the increasing geothermal industry.

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