EUDP Pilot Hole 1b

(j.nr 1887-0016)

CONCLUDING REPORT

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1 Summary

The EUDP project 'Pilot Hole 1b' has been concluded as a follow-on 'phase 1' and in preparation to a possible phase 2 of the project. The project has looked at geothermal production, a further detailing geothermal productivity in the subsurface and how a production management system should be implemented procedurally. Finally, the project has concluded on the business case for a geothermal energy system.

The project has not been able verify finally a positive business case. However, the project group in tantalising close to prove that geothermal energy can make a positive return, especially if the regulatory frame conditions with taxes and levies are adjusted. In addition, the project group can see from analysis of empirical data that costs of developing geothermal systems sequentially will decrease project costs dramatically.

The project has looked at establishing a road map for technological development of the surface system for extraction of heat. The vantage point have been the facilities in Copenhagen and Sønderborg, which are good facilities in their own right, but with areas where improvements can be made from technological obsolescence or improvement due to development of new technology.

As a project is being developed, the production management must be included to holistically look at the production during start-up, in the middle of the production life and when and how to address well productivity.

Lastly, the project looked at further detailing our knowledge of the Greater Copenhagen subsoil to verify not only which properties to address in phase 2, but also to broadly analyse and conclude on which knowledge to focus on in future development of geothermal energy to ascertain key properties and values.

2 Summary in Danish

EUDP projektet 'Pilot Hole 1b' er blevet afsluttet, som en videreførelse af fase 1 og som forberedelse til en mulig fase 2 af projektet. Projektet har kikket geotermisk produktion, en detaljering af undergrundens beskaffenhed for geotermisk produktion, samt opbygningen af grundstenene til produktionsstyring af geotermisk energi. Sidst, har projektet konkluderet på forretningsmodellen for et geotermisk energi system.

Projektet har ikke endegyldigt kunne konkludere at forretningsmodellen er god. Men, projektgruppen er meget tæt på at kunne vise en positiv forretningsmodel, specielt hvis rammevilkårene justeres jf energiafgifternes påvirkning af bl.a. el forbrug. Ydermere, har projektgruppen, via empirisk data, vist hvordan udviklingen af geotermiske anlæg sekventielt vil reducere projektomkostningerne dramatisk.

Projektet har udviklet en køreplan for den teknologiske udvikling af overfladesystemet. Udgangspunktet har været anlæggene i København og Sønderborg, som er gode anlæg, men med mulighed for forbedring pga af teknisk udløb eller udvikling af ny teknologi.

Når et projekt bliver udviklet skal produktionsledelse være et central element for at sikre produktionens 'vilkår' både under opstart, midt i produktionscyklussen og samt ved f.eks. levetidsforlængelse.

Afslutningsvis har projektet detaljeret vores viden omkring undergrunden under Storkøbenhavn, ikke mindst som forberedelse af fase 2, men også for bredt at analysere på hvilken viden fremtidig udvikling af geotermisk anlæg skal fokusere på og opsamle.

3 Background

HGS is looking at extending the number of geothermal production units. The expansion is rooted in Varmeplan København (see slide 10), the demographic development of Copenhagen, and not least the transition towards a CO_2-neutral, fossil-free future with targets set for 2030, 2035 and 2050.

A vision for 2030 includes installation of upwards of 300 MW heat from waste water and geothermal water.

HGS (a joint venture by HOFOR, VEKS and CTR) is investigating in the EUDP project 'Pilot Hole' the geothermal resource, by extraction of heat from the Gassum formation beneath Greater Copenhagen together with project partners Geoop, GEUS, Geo and Ross DK.

3.1 Project goal

The project target is to establish geothermal energy as a green and independent energy source complementing sun, wind and biomass in the bigger RE picture. We shall develop technical solutions and a business model for geothermal energy in combination with heat pumps, and including a consideration on energy storage. This way geothermal energy can become a significant green energy source in Denmark – and potentially leading to successful export business.

3.2 Project period

The project ran from 1 January 2016 to 31 January 2016.

3.3 Geothermal energy

Geothermal energy is heat from water (brine) reservoirs in the underground, and produced to surface via a production well. Heat is extracted through a heat exchanger and the cooled water in injected back into the reservoir via an injection well. The process is cyclic and the water is re-heated and produced again, and again, and …

4 Project set-up

The project 'pilot hole' is divided into 3 phases:

- Phase 1a focuses on the technical challenges in the subsurface, including location selection, well design, well engineering, and selection, adaptation and development of drilling equipment.
- Phase 1b focuses on subsurface geology, surface facilities and production management, processes and methodologies. The phase includes a work packages which summaries the business case.
- Phase 2 includes the actual drilling of a pilot hole which shall lead to coring in the Gassum Formation to validate the quality of the actual reservoir

This report is the conclusion of phase 1b.

Phase 2
Construction of a geothermal production facility (separate application, see Gantt chart)

<table>
<tr><td>Phase 1a

Awarded as j.no. 64015-0027

Study on well engineering and drilling technologies adapted to geothermal energy.</td><td>Phase 1b

Awarded as j.no 1887-0016

Study of surface facilities technologies, asset management and not least economic modelling based on a standardised, scalable geothermal facility.

This report concerns only this phase.</td></tr>
<tr><td colspan="2">Foundation

- Whitepaper for geothermal energy (Drejebog for geotermi)
- Risk disclosure (Risikoafdækning)
- Screening of 28 cities (Screening af 28 byer)
- Report on heat storage technologies, and big heat pumps in the District Heating grid (Udredning vedrørende varmelagringsteknologier og store varmepumper til brug i fjernvarmesystemet)
- Whitepaper on big heat pumps projects in the district heating system (Drejebog til store varmepumpeprojekter i fjernvarmesystemet)
- National garantee scheme (Garanti ordning)
- Own projects from the individual companies of the project group</td></tr>
</table>

Tabel 1 – Project phases

The foundation consists of work done by the project parties which forms the basis of the knowledge pool upon the project resides.

5 Project group

HGS hosts the project and has the systemic insights of how to utilise geothermal energy in a modern energy supplier's transmission and distribution systems. GEUS supports with knowledge of the subsurface, reservoir characteristics, modelling and simulation, as well as data collection and analysis of in-situ logging and core analysis. Geo and Ross DK provide experience with drilling technologies and procedural steps to run the planning and management of the drilling phase.

Project contacts		
Company	**Name**	**E-mail**
Ross DK	Jesper Peter Menne Baunsgaard	jesper.baunsgaard@rossoffshore.dk
Geoop	Lars Andersen	la@geoop.dk
GEUS	Lars Henrik Nielsen	lhn@geus.dk
HGS	Magnus Foged	mafo@hofor.dk
Geo	Kim Sillemann	ksi@geo.dk

Tabel 2 – Project Contacts

The above mentioned project contacts remain at disposal for further deliberation of the project and its results.

WP 1

GEOTHERMAL FACILITY

1 Extend / Scope of work

Surface facilities has until now been designed uniquely for each geothermal plant in Denmark. These are quite extensive in their footprint and with limitations in their setup regarding development of the plant.

Dansk Fjernvarmes Geotermiselskab was expected to head and perform most of the work on WP1, but the company was decided closed January 2016 and Ross Offshore took over project management for WP1.

HGS has through HOFOR done some work on a modular and expandable layout of a 10 MW geothermal surface facility with a heat pump plant assessing energy balances and costs. HOFOR has also presented main results to Ross – and some concept and component selections have been discussed. However, the contribution from HGS is based on experience from the existing geothermal plants and Ross has wished to pursue the idea of a further modularized design with a smaller footprint in this report.

Regarding "Osmotic Energy" it has been demonstrated that osmotic power can be produced with geothermal water from Sønderborg using existing membrane types. A next step can be to optimize the process including membrane design, test the concept on other geothermal water and to solve the problem of the disposal of the mixed water without risking a blocking of the injection well or creating environmental problems. The durability of the membranes must also be tested further.

Results from the work in HGS on facilities for urban plants on the distribution network benefitting from findings in the delayed SVAF project will be presented in later reports for the HGS license and the following represents ROSS thoughts on how to develop new more flexible surface facilities to fit urban development of geothermal energy.

1.1 Possible Solutions

The starting point is based on a principle of a 10MW sized facility with a 5 well template and with an economy of scale principle implemented. The focus has been on identifying critical paths and areas in subsections as mentioned below.

Planning

- Cost considerations and risk reducing measures.

Facility setup

- Flowline design and the possibility of a flexible system within the limitations.
- Footprint, Standard cellar construction, future expansion.

Components

- A look in to the possibility of a flexible modular concept and implementation of new technology.

Main findings and focus areas.

2 Design & Technology Matrix

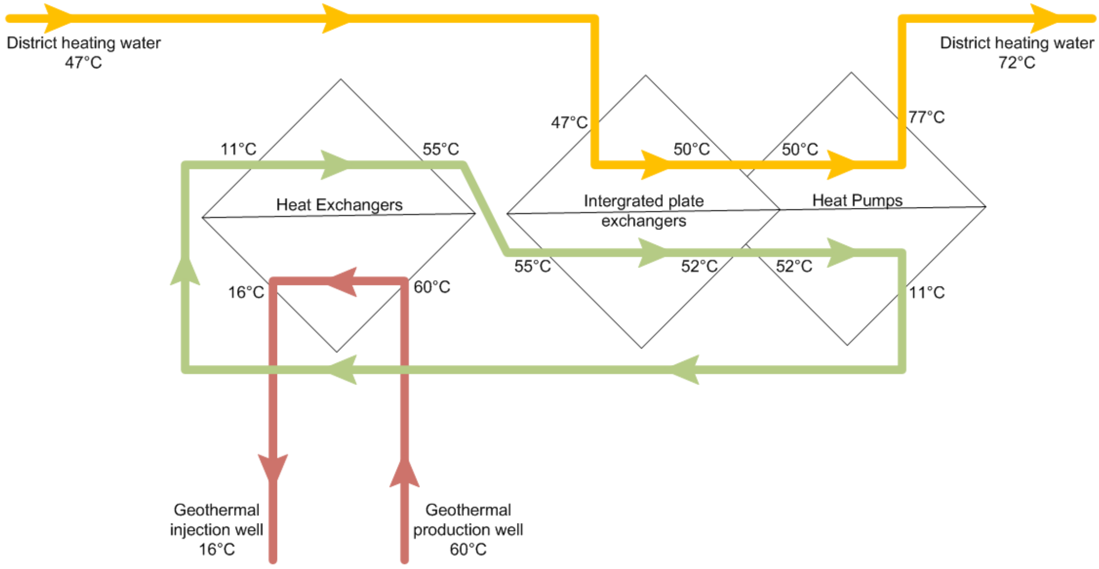
To control the interactions between facility layout, footprint and components a more regulated approach needed to be considered. Therefor a rough draft of a Design & Technology matrix has been developed. This is a tool to stepwise introduce new technology during a long-term plan and secure that not too many new technologies are introduced at the same time. New risks introduced with new technologies are also reduced. This will give a better chance of responding properly and in time if a risk develops into an actual situation.

	1 generation Amager (GDA)	2. generation (Estimated)	3. generation (Estimated)	4. generation (Estimated)	5. generation (Estimated)
No. of plants	1	3	5	5	10
No. of wells per plant	2	5	5	4	4
No. of wells in total	2	15	25	20	40
10 MW per new plant					
MW	14	30	50	50	100
Main facility components					
Filter system	Existing technology	New technology	Optimisation	Optimisation	Optimisation
Heat Exchangers	Existing technology	As 1st generation	New technology	Optimisation	Optimisation
Injection Pump	Existing technology	As 1st generation	New technology	Optimisation	Optimisation
Heat pumps / (SVAF)	Existing technology	As 1st generation	As 1st generation	New technology	Optimisation
ESP	Existing technology	As 1st generation	As 1st generation	As 1st generation	New technology
SCADA	Existing technology	As 1st generation	As 1st generation	As 1st generation	New technology
Flowline	Existing technology	Optimisation	Optimisation	Optimisation	Optimisation
Modular concept	N/A	Optimisation	Optimisation	Optimisation	Optimisation
Cellar construction	Existing technology	Optimisation	Optimisation	Optimisation	Optimisation

Figur 1 - Conceptual Design & Technology Matrix

3 Facility flowline

A contact was established to the Company AEA (Aktive Energi Anlæg A/S) who developed a standard 10MW flow diagram to use as a baseline. The diagram is useful for developing the various components within the system. AEA was then asked to look further in to designing a flowline setup including size and numbers of the components in the system. The extended design is still being processed by AEA and will be finalised post completion of this EUDP report.



Figur 2 - Standard 10MW flowline setup

4 Facility footprint

Limiting the footprint on the surface is done with respect to the interaction between the facility layout and the drilling operation during the construction phase. The entire objective is to minimise the footprint in order to fit smaller urban areas.

4.1 Flexibility

A big part of the project is used to examine and launch ideas about how to implement a modular concept. There are several positive reasons for choosing to pursue this idea. Limited space, easy to move around, and standardisation are some of them. The modular concept is mainly looking into implementation of standard sized intermodal containers. But there is an awareness about that some components are probably not possible to fit inside a standard container. Here it would be interesting to look in to a possible alternative way of creating a modular system.

Another interesting aspect to look at would be to examine the possibility of a flexible system where modules can be added or removed to fit the production profile of the plant.

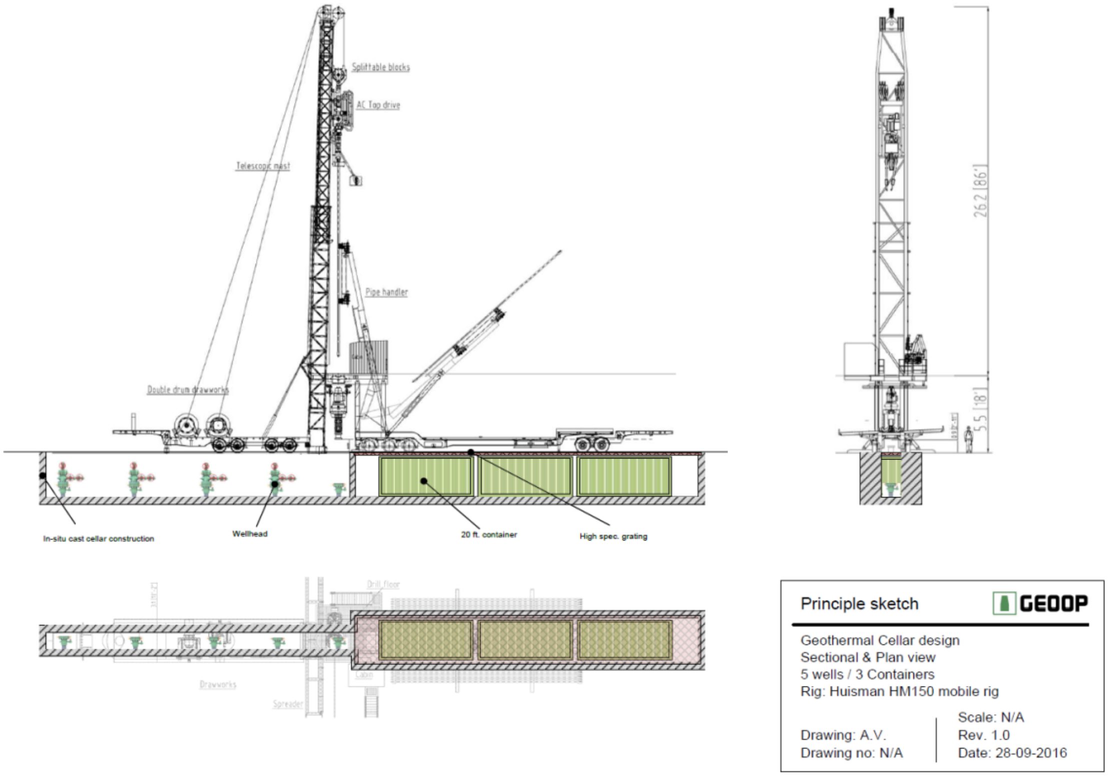
4.2 Drilling rig

When looking in to minimising the facility footprint one of the steps were to look into minimising the footprint of the drilling rig. Using a smaller lightweight rig is obvious for this purpose and also contributes a great deal to minimising the entire operational cost during the construction phase. One of the biggest posts on a drilling budget is normally the rig. However the choice of rig is dependent on expected drilling issues.

A contact to the Dutch company Huisman has been established and a truck mounted lightweight rig already exists. This rig can be even further developed to fit possible standards if needed.

4.3 Cellar Construction

Standardising the use of intermodal containers would create a possibility of developing a system where some of the components could be placed subsurface to limit the footprint above ground level. This could be done in connection with the cellar or in a separate construction. A draft version of such a construction has been made with a 5 well template, to fit the slim designed truck mounted drilling rig from Huisman and with space for 2 or 3 intermodal containers. The idea has to be challenged a lot more in order to determine the feasibility of the entire model though.



Figur 3 – Light rig

5 Components

5.1 New filer systems

The company LiqTech International A/S produces various industrial filter systems. Among others a ceramic type filter for industrial waste water. Looking into development of a modular filter system that will fit inside an intermodal container has been initiated. LiqTech is quite progressive in terms of developing a system and has already made a draft of a proposed filter system. In conjunction with this internal discussions and conversations within the EUDP group regarding the possibility of filtering the geothermal brine has started.

5.2 Heat exchangers & Heat pumps

Initial correspondence with the Swedish company Alfa Laval AB regarding the possibility of developing a fit for purpose modular heat exchanger system has been established. However it is too early to conclude anything from that yet. Alpha Laval is quite positive in their approach to the project though.

Looking in to optimising or developing a new standard for heat pumps it has been essential to follow the concurrent running EUDP project, SVAF (Store VArmepumper til Fjernvarmen). This is a project that has focus on the subject in terms of electrical heat pumps. However there is a delay on this project which means that it hasn't been possible to derive useful information from it yet. This will be initiated at a later stage. Weather future heat pumps should be electrical or run or another propellant is still to be challenged.

5.3 ESPs (Electrical Submersible Pumps) & SCADA systems

Work Package 3 covers the Production management. ESPs and SCADA systems in terms of monitoring of the system are dealt with in WP3. Both subjects are a big part of the optimisation process. In WP3 a contact to the Danish company Grundfos has been established. Grundfos might be able to develop ESPs for the geothermal industry. By looking in to the use of an ESP supplier outside the conventional oil and gas industry will without a doubt introduce a great cost reduction for future geothermal projects.

5.4 Injection Pumps

Conventionally ESPs have been used on the surface as injection pumps since they normally possess the properties needed for injection of the geothermal brine. Developing a new series of ESPs for the geothermal industry also gives rise to the idea of using an alternative type of injection pumps. Again with cost reduction as the main focus. Grundfos might be able to convert a standard booster pump from their programme to fit a geothermal system. In practice this could be done by e.g. using 2 or 3 pumps with specifications like 100 m3/hr. at 70-80 bar. An extra pump would bring a certain extra reliability into the system. It will also be interesting to look in to the energy consumption, efficiency and optimisation of a system like this.

6 Further Work

- A more detailed plan of the entire approach/plan of the development.
- A more detailed flowline setup design by AEA.
- In general further work concerning the development of the components.
    - More knowledge about ceramic filters and how to implement them properly in a future system.
    - Heat exchanger systems.
    - Heat pumps.
    - ESPs & Injection pump systems.
    - SCADA system monitoring.

WP 2

SUBSURFACE

1 Introduction

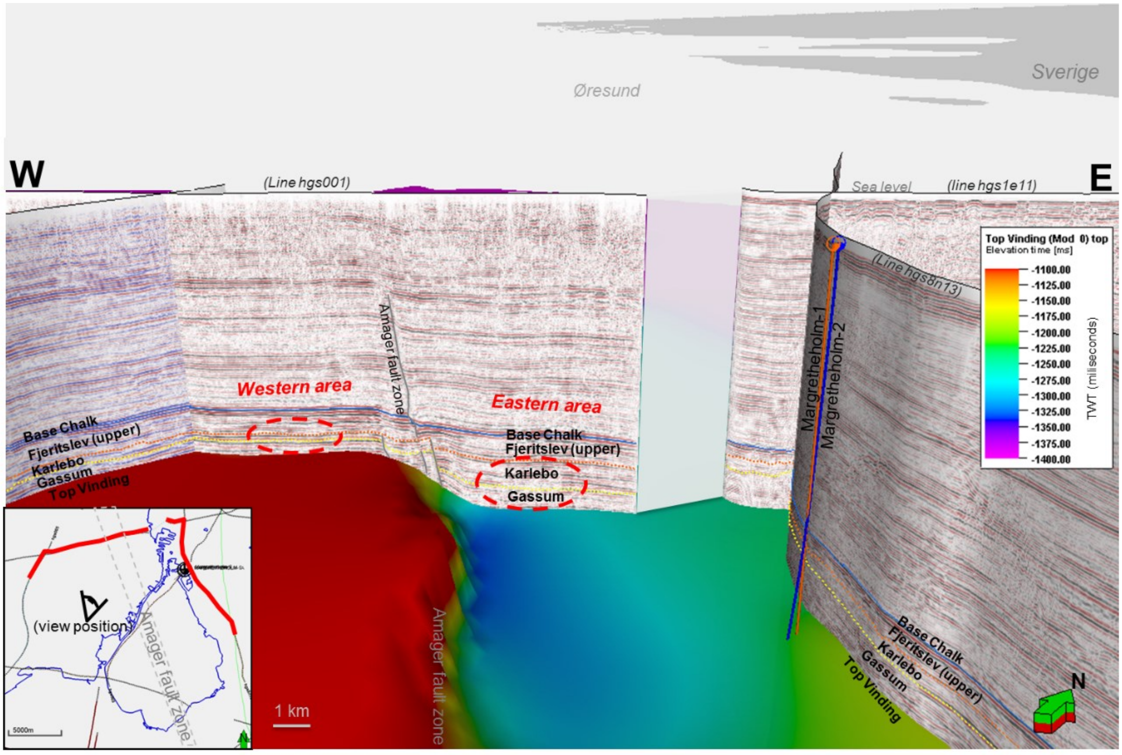
Work Package 2 (WP2) deals with the subsurface and provides a prognosis of the geothermal potential for the Gassum Formation and the Karlebo Member in two areas of interest within northern Copenhagen. The two areas were selected as being relevant for geothermal heat exploration in Phase 1a of the project based on infrastructure considerations (e.g. positions of existing district heating plants, current and future district heat networks and coupling points) as well as the composition of the subsurface in the larger Copenhagen area.

The Gassum Formation and the Karlebo Member were treated as a composite unit in Phase 1a of the project as the boundary between them is difficult to define in existing seismic data. However, the recognition of a boundary between the two units has been possible in the present phase of the project, based on a detailed and comprehensive interpretation of the seismic lines closest to the two areas of interest, guided by a sequence stratigraphic interpretation of the composite succession. As a consequence of this, more accurate estimates of depth, thickness and reservoir properties are given for both the Gassum Formation and the Karlebo Member in the present report. The Karlebo Member consists of sandstone beds that are petrographically very similar to those in the Gassum Formation, but are in general separated by thicker mudstone intervals than the sandstones are in the Gassum Formation. The Karlebo Member forms the lower part of the Fjerritslev Formation in northern and eastern Zealand. The remaining upper part of the Fjerritslev Formation in Zealand, as well as the entire Fjerritslev Formation in Jut-land, consists almost entirely of mudstones and claystones. Petrophysical log data from deep wells shows that the Gassum Formation in general contains the largest amount of reservoir sandstones and is thus considered to be the main target for geothermal recovery in the two areas of interest.

A secondary scope of WP2 is to evaluate if the clay mineralogy in clayey intervals of the Gassum Formation, the Karlebo Member, and especially in the thick clay-dominated part of the Fjerritslev Formation (i.e. the overburden of the potential sandstone reservoirs) may cause a particular drilling risk, e.g. due to a high content of reactive clay minerals. Finally, the geological data form input for considerations about development of drilling equipment, selection of well completion techniques and logging tools and for financial assessment of the profitability of incorporating a geothermal plant in the district heating system; all subjects, which are reported in other work packages and/or are to be dealt with in Phase 2 of the project.

2 Areas of interest

The two areas of interest are separated by a NNW–SSE striking fault, the Amager Fault, which form part of a major fault zone running from north of Zealand into the HGS license area as outlined in Phase 1a of the project. GEUS´ standard "rule of thumb" is to place a geothermal well at a distance of minimum 2 km from a recognized fault as modelling indicates that the reservoir flow is not influenced if such a distance is kept, even if the fault is modelled as a non-permeable barrier (which it seldom is). The distance of 2 km from the areas of interest to the fault is thus a very conservative precaution. The de-tailed seismic mapping undertaken in the present phase of the project reveals that the fault should instead be described as a fault zone, approximately 1 km wide and containing a number of faults with different displacement. The Gassum Formation and the Karlebo Member are thicker and occur at a deeper level in the eastern area compared to the western area, indicating that down-faulting towards the east took place during deposition (Fig. 1). In contrast, the overlying, clay-dominated part of the Fjerritslev Formation shows no marked thickness variation across the fault, thereby indicating that faulting had ceased when this part of the succession was deposited. The fault zone was most likely affected by a later compressional tectonic phase of Cretaceous age or younger as seen by the occurrence of vertical faults, which separate minor inversion ridges and extend up into the Cretaceous chalk. Minor progradational seismic reflectors and subtle troughs are observed within the Gassum Formation and the Karlebo Member and point towards a dynamic depositional regime. Based on GEUS´ general knowledge of the Upper Triassic–Lower Jurassic succession in the rim of the Norwegian-Danish Basin, such features may be interpreted as reflecting depositional and erosional processes within near-coastal and fluvial environments.



Figur 4 – East / West

Figure 4. Seismic lines in 3D view seen towards northern Copenhagen and Margretheholm in northern Amager. View position and direction are marked on the inserted location map in lower left corner of the figure as is the overall trend of the Amager Fault zone. The colored surface reflects the depth to and morphology of the Top Vinding surface corresponding to the base of the Gassum Formation. The surface clearly illustrates the fault controlled deeper position of the eastern area compared to the western area. It is also evident that the thickness of the Gassum Formation and the Karlebo Member, marked on the seismic profiles, becomes considerably thicker from the western area across the Amager Fault zone to the eastern area. In contrast, the overlying, clay-dominated part of Fjerritslev Formation shows no marked thickness variation across the fault, indicating that faulting had ceased when this part of the succession was formed. Depths to the Top Vinding surface is given in TWT (see inserted scale).

The Gassum Formation is around 200 m thick and has its top c. 2000 m below sea level in the eastern area whereas it is around 150 m thick and has it top c. 1750 m below sea level in the western area (Table 1). The porosity and permeability values for the Gassum Formation are estimated to be slightly lower in the eastern area compared to the western area, perhaps related to the deeper burial depth of the eastern area as permeability and porosity in general decrease with increasing depth. The mean porosity and permeability of the reservoir sandstones in the eastern area are thus estimated to 21% and 313 mD, respectively, whereas they are estimated to 25% and 375 mD for the western area (Table 1).

The proportion of reservoir sandstone in the formation (Potential reservoir sand in Table 1) is estimated to 80 m and 75 m for the eastern area and western area, respectively. In addition, the reservoir transmissivity for the Gassum Formation is estimated to 25 Darcy-meter for the eastern area and 28 Darcy-meter for the western area. The reservoir transmissivity is an important parameter as it expresses the performance of the reservoir, given by multiplying the estimated thickness of potential reservoir sand with the estimated reservoir permeability. As a rule of thumb, the reservoir transmissivity of a sandstone interval should be greater than 10 Darcy-meter in order to constitute a potential geothermal reservoir in the Danish area. Thus, the Gassum Formation is considered suitable for geothermal exploitation in both areas.

Although the estimated porosity, permeability and transmissivity values are slightly high-er in the western area this does not necessary qualify the reservoir properties of the Gassum Formation as being best in this area. This is because the geothermal water of the Gassum Formation in the eastern area benefits from having higher temperatures than in the western area (65 °C contra 57 °C, respectively, in the middle of the Gassum Formation, Table 1) as consequence of the deeper subsurface location of the Gassum Formation in this area.

The secondary reservoir target, the Karlebo Member, is c. 200 m thick and has its top c. 1800 m below sea level in the eastern area whereas it is around 100 m thick and has it top c. 1650 m below sea level in the western area (Table 1). These depths imply that temperatures of 54 °C and 59 °C are attributed to the middle of the Karlebo Member in the western area and eastern area, respectively. The depth difference of 150 m between the western area and the eastern area is not reflected by the estimated porosity and permeability values. In fact, the permeability is estimated to be higher in the eastern area than the western area, 375 mD contra 300 mD, whereas the porosity is almost the same; 23% for the eastern area and 22% for the western area (Table 1). Furthermore, the pro-portion of reservoir sandstone in the member is estimated to be twice as high in the eastern area compared to the western area (40 m contra 20 m as shown in Table 1). This has a major impact on the reservoir transmissivity, which is estimated to be 15 Dar-cy-meter for the eastern area whereas it is 6 Darcy-meter for the western area. Seen in isolation, the Karlebo Member can therefore not be considered as a suitable geothermal reservoir in the western area based on the present assessments and calculations, as outlined in Vosgerau et al. 2016. Nevertheless, it may contribute to the geothermal production if geothermal energy is produced simultaneously from the Gassum Formation and the directly overlying Karlebo Member. This is also the case in the eastern area where the Karlebo Member furthermore forms a secondary geothermal reservoir target in its own.

The reservoir estimates in Table 1 largely build on petrophysical evaluations of relevant log-data from deep wells combined with porosity and permeability measurements on core material. With respect to the western area, primarily data from Lavø-1 along with data from the Stenlille and Margretheholm wells were used, whereas the reservoir properties of the eastern area were predicted mainly on the basis of data from the Margretheholm wells and the Karlebo-1A well.

		Gassum Fm		**Karlebo Mb**	
		Western area	Eastern area	Western area	Eastern area
Macro reservoir parameters					
Depth to top	[MBSL]	1750	2000	1650	1800
Thickness	[m]	150	200	100	200

Sandstone proportion					
Thickness of Gross sand	[m]	101	100	40	80
Thickness of potential reservoir sand[1]	[m]	75	80	20	40
Potential reservoir sand/formation[2]		0.5	0.4	0.2	0.2
Potential reservoir sand/Gross sand[3]		0.7	0.8	0.5	0.5
Water conducting properties (reservoir sand)					
Porosity	[%]	25	21	23	22
Gas-permeability	[mD]	300	250	240	300
Reservoir-permeability[4]	[mD]	375	313	300	375
Reservoir-transmissivity (Kh)[5]	[Dm]	28	25	6	15
Temperature					
Temperature[6]	[°C]	57	65	54	59
Texture (sandstone)					
Dominating grain size /sorting/roundness		Fine to medium, well sorted, subrounded		Very fine to fine, moderately to well sorted, subrounded	

Tabel 3 – Gassum / Karlebo

Table 1. Estimated reservoir values for the Gassum Formation and the Karlebo Member in the two areas of interest. Uncertainty estimates of the shown parameter values are given in Vosgerau et al. (2016).

1 Thickness of Potential reservoir sand is estimated on the basis of cut-off values on Vshale (< 30%) and log-porosity (> 15%).

2 Thickness of Potential reservoir sand divided with thickness of lithostratigraphic unit.

3 Thickness of Potential reservoir sand divided with thickness of Gross sand.

4 Reservoir-permeability is the permeability which is expected to be measured in connection to a pump test or well test. The reservoir-permeability is estimated by multiplying the Gas-permeability with an upscaling factor of 1.25.

5 Reservoir-transmissivity is estimated on the basis of an interpretation of log data and analysis core data. The Reservoir-transmissivity is upscaled to reservoir conditions.

6 Temperature is the estimated temperature in the middle of the Gassum Fm/Karlebo Mb.

3 Composition of the reservoir sandstones

In general, the sandstones in the Gassum Formation are mainly fine- to medium-grained and well sorted, whereas they are very fine- to fine-grained and moderately to well sorted in the Karlebo Member. Individual sand grains are generally subrounded in both the Gassum Formation and the Karlebo Member. Thin section and scanning electron microscopy (SEM) analysis of sandstone material from Stenlille cores and cutting samples from the Margretheholm-1 well furthermore reveals that sandstones from the Gassum Formation and the Karlebo Member have a comparable and very mature mineralogy with detrital quartz being the dominant component (on average constituting 81% of sand grains). Feldspar is a minor to common component (averaging 6%) and the feldspar con-tent is on average twice as high in the Karlebo Member as in the Gassum Formation. Mica, organic matter, clay and heavy minerals are usually rare. The overall content of authigenic minerals is rather low (averaging 8%) and includes among others small scat-tered siderite rhombs in the Karlebo Member and rare to minor kaolinite, mainly in the Gassum Formation. However, kaolinite infilled all sandstone pores in a single cutting fragment from the Gassum Formation in the Margretheholm-1 well, indicating that in certain levels this mineral may reduce porosity and permeability. Carbonate cementation is rare but may be pronounced in certain intervals as a cutting fragment from the Gassum Formation showed a calcite content of 45%. Quartz overgrowths are volumetrically minor but slightly more pronounced in sandstone material from the Margretheholm-1 well than from the Stenlille wells, in accordance with an approximately 300 m deeper burial depth of the succession in the Margretheholm area than the Stenlille area. Differences in depth and diagensis, influencing the reservoir properties, were therefore taken into account when predicting the reservoir properties of the two areas of interest on the basis of Stenlille data.

4 Reservoir model

The reservoir data in Table 1 and regional mapping of the depth to the top and base of the Gassum Formation and the Karlebo Member, compiled on the basis of seismic data, have been used to set up a reservoir model in order to simulate flow rates and the timespan before cooled water from injection wells reach the production wells. In these simulations, geothermal plants are considered which have two deviated production wells and two deviated injection wells together with a vertical spud well, which is also used for injection. The reservoir simulations were run for a location in each of the prognosis are-as. A well spacing of 1500 m was used for initial screening but simulation runs with different well spacing (done in Work Package 3) showed that distances could be kept as low as 900 m without any cold-water breakthrough at the production wells within the simulation run of 25 years. Short distances are preferred as it implies a smaller inclination of the wells in order to obtain the necessary distance at reservoir level, if the wells of the geothermal plant emanate from the same location. This may lower drilling risks as drill-ing in general becomes more complicated with increasing angle of drilling.

For the initial screening of the two locations, a constant production rate of 100 m3/h pr. production well and 66.66 m3/h pr. injection well was simulated in order to give a total production/injection of 4800 m3/day for the two production wells and the three injection wells. In deployment, higher well rates can be obtained, as long as the injection pressure is kept below the formation fracture pressure. This can be optimized by well completion and well inclination.

The production-/injection-index (WPI) was calculated in order to compare the productivity and injectivity for the two locations. The WPI is the ratio between fluid rate and the effective drawdown in the well, and is a measure of the fluid output/input to the reservoir pr. bar applied overpressure to the well. The WPI is a normalized number, which makes it easy to compare the productivity/injectivity for wells operated at different rates. In gen-eral, WPI's for the eastern location are approximately 30% higher relative to the western location, which means that production and injection rates are 30% higher for the same pressure drawdown. The difference in WPI is a combination of differences in reservoir parameter values and reservoir thickness.

For both locations the simulated injection bottom hole pressure (BHP), which is the necessary pressure in the bottom of the well to force the fluid volume from the well into the reservoir, never exceeded the formation fracture pressure. The eastern location has a more favorable production temperature profile due to the deeper position of the reservoir.

To illustrate the influence of the Amager Fault, a simulation case was run for the western location (located c. 2 km west of the fault). Although the fault was set to be closed for flow and pressure communication in the simulation, this did not reveal any effect on the WPI's or on the production temperature profile.

Overall, the model simulations showed suitable production capacities for both locations but with the eastern location being most favorable because of higher WPI's and tempera-ture and thicker reservoir intervals, which delays cold-water breakthrough as the cold-water front is divided over a higher reservoir interval.

5 Clay mineralogy

Clay mineralogical analysis of clayey intervals in the Gassum Formation, the Karlebo Member, and the overlying clay-dominated part of the Fjerritslev Formation show a large-ly uniform clay mineralogical composition with kaolinite as the dominant clay mineral followed by mixed-layer minerals, which appear to be interstratified illite and vermiculite. Smectite and chlorite are not detected in any of the samples. Kaolinite may occur both as a detrital mineral and as an authigenic mineral formed during diagenesis. The latter is reported below from some sandstone samples. Previous studies show that kaolinite is commonly a dominant clay mineral in the Upper Triassic and Lower Jurassic deposits in the Danish Basin. There are slight differences in the clay mineral assemblage between Margretheholm-1 and Karlebo-1A (the wells representing a fairly close position to the palaeoshoreline) and Kvols-1 and -2A, where the sediments were deposited in deeper water farther from the coastline. The data suggest that kaolinite decreases and the other minerals increase in amount away from the coastline (Table 2).

In the samples used for clay-mineral analysis the amount of clay-sized particles has been determined (right column in Table 2). The data values show that most of the mud-stones contain more silt than clay. The samples from Kvols-1 and -2A are bulk samples, whereas those from Karlebo-1A and Margretheholm-1 are picked cuttings. This difference in methods produces a bias towards more fine-grained lithologies for the latter method.

The bulk-mineralogy has been examined in all the samples used for clay mineral anal-sis, as well as several additional samples. The bulk-mineralogy provides information on the minerals in the sand- and silt-fractions. The analyses show that quartz is the most common mineral and that traces of feldspar (microcline and albite) occur in many samples. Kaolinite and illite, or mica, is present in most samples and are probably detrital minerals to a large extent. Calcite appears to originate mainly from caving of overlying Cretaceous chalk. The minerals pyrite, siderite, and ankerite are interpreted as formed during diagenesis, and occur in varying, but small amounts.

Lithostratigrahpy	**Well**	**Number of analyses**	**Clay content (wt-%)**			**Grain-size fraction (wt-%)**	
			Kaolinite	Vermiculite + mixed layer min.	Illite, mica	Clay	Silt and very fine sand
Fjerritslev Fm above Karlebo Mb	Margretheholm-1A	3	35-39	40-44	15-19	50	50
	Karlebo-1A	4	35-39	40-44	15-19	55	45
	Kvols-1, Kvols-2A	10	35-39	45-49	10-14	45	55
Karlebo Mb	Margretheholm-1A	4	40-44	35-39	10-14	32	68
	Karlebo-1A	2	40-44	40-44	15-19	44	44
Gassum Fm	Margretheholm-1A	3	45-40	30-34	10-14	40	60

	Karlebo-1A	3	30-34	45-49	15-19	52	48

Tabel 4 – Clay minerals

Table 2. *The average content of clay minerals in the Fjerritslev Formation, the Karlebo Member and the Gassum Formation is shown. The data values demonstrate the very small variation in the clay mineral assemblage between the units. More detailed information is provided in Vosgerau et al. (2016). Please note the low number of analyses, which means that average values in the table may change if just a few more analyses were added. The right-hand columns show the content of clay-sized particles (mostly clay minerals) and the amount of silt and very fine-grained sand in the samples.*

The clay mineralogical composition in itself does not give rise to particular drilling risk concerns, since clay swelling during drilling in general is attributed to smectite, a very reactive clay mineral which has not been encountered in the present analysis. A review of completion reports of selected wells reveals that drilling problems related to swelling, sticking, caving and solubility in water do occur in the Fjerritslev Formation and locally in clayey intervals of the Gassum Formation. An overview of this information has been compiled from the completion reports and made available as an appendix in Vosgerau et al. (2016). However, it has not been possible to link a specific clay mineralogical composition to the intervals where these phenomena have been observed. Intervals of reactive clays, not covered by the present sampling, may of course be present. However, it is also possible that the observed drilling problems should be linked to an inappropriate composition of the drilling mud in relation to the clay mineralogy. A minor literature study on formation damage control emphasizes the importance of having a proper brine con-centration of the fluids used during drilling and completion of wells and workover operations (in Vosgerau et al. 2016). Swelling of clay particles is more likely to occur when the clay is exposed to aqueous solutions with brine concentrations below a critical salt con-centration. Furthermore, a low salt concentration and/or high fluid velocities may cause a release of fine-grained minerals, primarily kaolinite, which may lead to plugging of pore throats and thus reduced permeability in the reservoir sandstones.

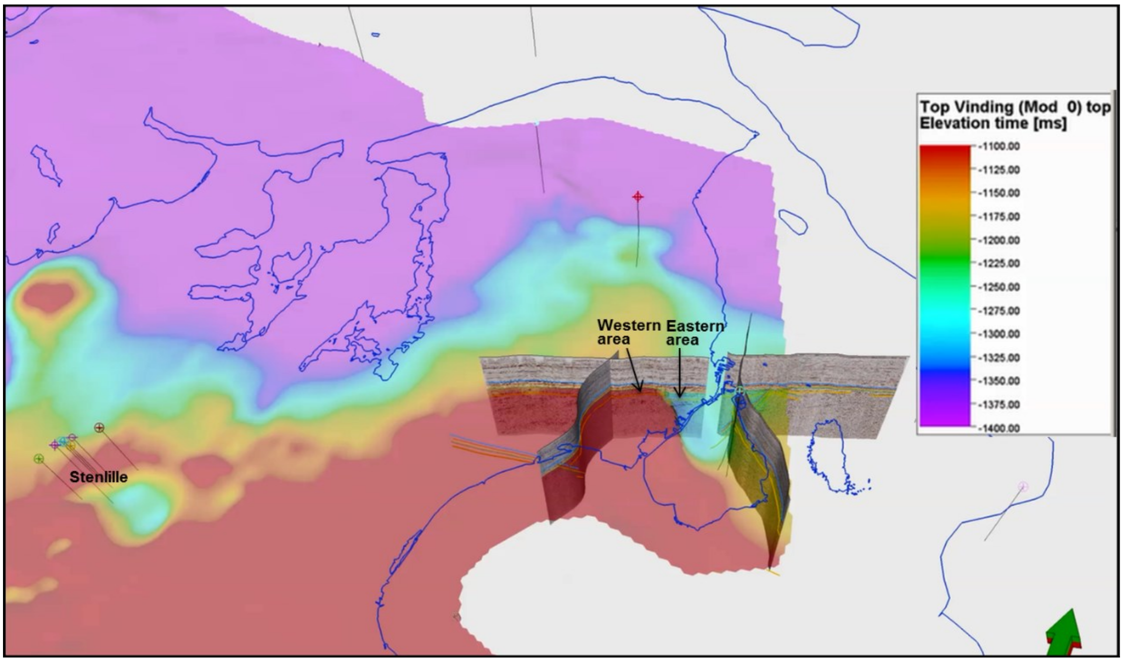
The obtained knowledge of the clay mineralogy may therefore provide important information concerning the composition of drilling mud etc. when the clayey intervals of the Fjerritslev Formation, the Karlebo Member and the Gassum Formation are to be drilled in the future.

6 Stratigraphic framework and offset data

The number of wells in eastern Zealand is limited to Margretheholm-1/1A/2, Karlebo-1/1A and Lavø-1 from which no cores of reservoir sandstones exist. Furthermore, the petrophysical log data from Lavø-1 are of poor quality. However, a large amount of petrophysical log data of good quality, as well as core data, exist from the Stenlille area which is situated in the central part of Zealand, c. 60 km west of the areas of interest. Twenty deep wells in the area provide information of the Karlebo Member and Gassum Formation. The wells were drilled to test the Gassum Formation (reservoir) and Fjer-ritslev Formation (seal) prior to and during the establishment of the gas storage facility site at Stenlille. As outlined above, comprehensive analyses have been undertaken on the high-quality data from Stenlille and extrapolated to eastern Zealand in order to prognosticate the reservoir properties in the two areas of interest.

Prior to these analyses, an important task was to substantiate the relevance of the Stenlille data as an analogue for the Gassum Formation and the Karlebo Member in the two areas of interest. Several factors pointed towards this being the case. A sequence strati-graphic subdivision of the Gassum Formation – Fjerritslev Formation interval, based primarily on vertical log motifs from deep wells combined with comprehensive biostratigraphic analyses and interpretations of depositional environment of cores, showed that several packages of sandstones and intervening mudstones can be correlated between the wells from Stenlille and the wells in eastern Zealand. Consequently, these sedimentary packages are of regional extent and it is therefore likely that they are also present in the subsurface of the prognosis areas. In the selection of relevant analogue data from Stenlille (especially core data), emphasis has in particular been placed on those data which cover the regional sedimentary packages. The base of the Gassum Formation is regional mapped based on seismic data and appears as a northward, down-dipping flank along which both the Stenlille area and the western prognosis area occur at a comparable down-flank position (Fig. 2). This indicates an overall similar paleogeographic setting and probably some similar depositional environments for the Stenlille area and the west-ern prognosis area during the deposition of the Gassum Formation and Karlebo Member thereby stressing the relevance of the Stenlille data for especially the western prognosis area. The presence of cysts from marine phytoplankton (dinoflagellates, acritarchs, prasinophytes) in nearly all of the palynological samples shows that the sedimentary succession (Gassum Formation, Karlebo Member, Fjerritslev Formation) was deposited in a marine to marginal marine environment; lateral continuity of sedimentary packages is in general large in marine settings.

Furthermore, radiometric dating based on U–Pb in detrital zircon grains from the Gassum Formation and Karlebo Member indicate that both the Stenlille area and “Margretheholm area” were sourced by reworked sediments of the Lower Triassic Bunter Sandstone Formation on the Ringkøbing–Fyn High and to a lesser degree from erosion of the crystalline rocks in Fennoscandia.



Tabel 5 - Morphology

Figure 2. *The figure illustrates the depth to and morphology of the Top Vinding surface, corre-sponding to the base of the Gassum Formation, in central and eastern Zealand. Vertical “nee-dles” mark the positon of existing wells. The surface appears as a northward, down-dipping flank along which both the Stenlille area and the western prospect area occur in a comparable down-flank position, thereby indicating an overall similar paleogeographic and depositional set-ting. Depths to the Top Vinding surface is given in two-way time (TWT, see inserted scale).*

As outlined above, the relevance of the Stenlille data was confirmed by the outcome of the petrographic analysis of sandstone material from the Gassum Formation and the Karlebo Member in the Stenlille wells and the Margretheholm-1 well, which show an overall similar mature mineralogy with high quartz content and low feldspar content. Compared to the Gassum Formation in Jutland, both the Gassum Formation and the Karlebo Member in Zealand have a much more mature mineralogy. They are therefore expected to be less reactive to water injection, which may induce feldspar alteration and dissolution after slight changes in brine composition and flux.

For the final selection of a borehole location, considerations of flow rate versus temperature, differences in drilling costs related to different drilling depths etc. as well as non-geological related parameters such as optimal position in relation to district heating infrastructure has to be taken into account. The present report of WP2 compiles and documents relevant subsurface data and analysis of these and thereby forms a solid foundation for delivering the geological input for selection of the final location of an exploration well in Phase 2 of the project.

Although the present analyses suggest that the many detailed well data from the Stenlille area can be used to predict the reservoir properties in the two areas of interest, extrapolation of the Stenlille data as far as to eastern Zealand is associated with some uncertainties. A new well in the Copenhagen area, from which cores, petrophysical log data and hydraulic test data of high quality are collected and subsequently analysed, will considerably increase our ability to predict the reservoir properties of the Gassum Formation and the Karlebo Member in the greater Copenhagen area. Hence, the economic risk associated with the establishment of a geothermal plant will be reduced - not only in the Copenhagen area but in eastern Zealand as a whole. Furthermore, a new well will enable comparison of obtained core analyses data (including direct porosity and permeability measurements) with petrophysical log data and hydraulic test data from intervals of penetrated reservoir sandstone, and will thus provide a unique possibility to verify to what extent traditional petrophysical log data can be used to estimate the reservoir properties of geothermal sandstones of the Gassum Formation and the Karlebo Member in eastern Zealand. This knowledge is important for evaluation of the geothermal potential in a given area based on log data from existing wells, and for selecting suitable log tools for estimating porosity, permeability and injectivity of reservoir sandstones in connection to the performance of geothermal wells in the future.

7 References

Vosgerau, H., Gregersen, U., Hjuler, M.L., Holmslykke, H.D., Kristensen, L., Lindström, S., Mathiesen, A., Nielsen, C.M., Olivarius, M., Pedersen, G.K. & Nielsen, L.H. 2016: Reservoir prognosis of the Gassum Formation and the Karlebo Member within two areas of interest in northern Copenhagen. The EUDP project "Geothermal pilot well, phase 1b". Danmarks og Grønlands Geologiske Undersøgelse Rapport 2016/56.

WP 3

PRODUCTION MANAGEMENT

1 Summary

The work in Work Package 3 has been focussed on identifying the practical implementation of the requirements dictated by the policies, standards and work instructions that must be specified and viewed in the context of a comprehensive Geothermal Operators Management System.

The outline structure of the Management System has been defined.

The following topics have been investigated:

1. Plant Design and Operating Philosophy
2. Reservoir Management
3. Reservoir Completion Specification & Selection
4. Production Technology and Monitoring
5. Drilling and Completion Operations
6. Production Assurance and Remediation

Since a full Management System must necessarily cover all aspects of an entity, only a subsection of the Management System has been addressed in this project, specifically those topics relevant to ensuring optimised production from a geothermal facility throughout the projected lifetime.

2 Context – Geothermal Operator Management System

The Geothermal Management System is defined in three levels:

Level 1 – Policies and Principles, defining the Operators identity and values. Defines the values guiding conduct. Examples of typical policies are:

- Code of Conduct
- Core Values
- HSE Policy
- Quality Policy
- Etc.

Level 2 – Processes, defining the flow of operations and tasks. Links to detailed Level 3 instructions for how work must be carried

- Quality and compliance control
- Management of Change
- Process Management
- Emergency Preparedness Manual
- Job Descriptions
- HSE Manual
- Etc.

Level 3 – Work Instructions, Standards, Guidelines. Detailed instructions for conducting daily operations in the company.

- Casing Design Manual
- Daily Productions Guidelines
- Well Intervention Manual
- Risk Evaluation and Risk Register
- Well Integrity Manual

– Etc.

This is the simplest definition of the management system pyramid; other implementations add layers for greater level of detail and more accurate definitions.

3 Results

The focus in Work Package 3 has been on defining the input required to build specific elements of the Geothermal Operator Management System. A full management system is obviously outside the scope of this project; however the following items have been the subject of investigations during the project:

Geothermal Operator Management System		
Level 1 - Policy	**Level 2 – Process**	**Level 3 – Work Instructions**
(Code of Conduct)	Operating Philosophy	Plant Design
		Reservoir Management
		Reservoir Completion & Selection
		Production Technology & Monitoring
		Drilling & Completion Operations
		Production Assurance & Remediation

Tabel 6 – Management system

3.1 Level 1 – Policy

3.1.1 Code of Conduct

Code of Conduct is one several policies that governs how Level-2 and Level-3 processes and guidelines are implemented. It is listed here as an example. No work has been done on this subject as it is too broad a subject for the purpose of this project.

3.2 Level 2 – Process

3.3 Operating Philosophy

An outline philosophy of operation ensuring the most efficient exploitation of the geothermal resources utilising optimised well spacing and production parameters.

3.4 Level 3 – Work Instructions, Guidelines, Standards etc

3.4.1 Plant Design

Based on input from WP4, a well configuration of 2+3 has been defined. Planned production rates and well configuration has been investigated to optimise resource utilisation and plant operation.

3.4.2 Reservoir Management

Well placement, distances and monitoring has been evaluated and outlines for ensuring proper reservoir management has been documented.

3.4.3 Reservoir Completion & Selection

Specifications required confidently specifying and selecting reservoir completion as well as an evaluation of pros and cons of the potential technical solutions.

3.4.4 Production Technology & Monitoring

Options and requirements for comprehensively monitor well and reservoir performance.

3.4.5 Drilling & Completion Operations

The requirements to efficiently, design, plan and construct fit for purpose geothermal wells optimising production and maintaining a cost efficient operation during well construction.

3.4.6 Production Assurance & Remediation

Production assurance and remediation is required in order to, through the utilisation of input from the well surveillance in section 3.4.4 and implementing best practices, ensure continuous production throughout the planned lifetime of the geothermal facility.

WP 4

ECONOMIC MODELS

1 Introduction

Aim of work package 4 (WP4) has been to analyse:

- the economics of a new design of a geothermal plant
- economy of scale
- the influence of ownership and financing.

Below is given a short report on the findings of the work.

2 Economics of a new plant design

The new design of the geothermal project is to build 10 standardized plants each having a heat production capacity of 10 MW from the geothermal reservoir. Other characteristics of the new plant design are

- Using small locations close to the district heating grid
- To reduce the depth of the wells from 2.700 meter to about 2.100 meter by using the Gassum formation as a reservoir instead of the Bunter formation.

The new design is having the Nordhavn location design as a reference. In the table below, the new design based on a portfolio of small plants and the Nordhavn design are compared on main characteristics.

3 Comparison of new and old design of geothermal plant

	Pilot Hole (new)	**Nordhavn design**
Capacity from the ground	10 x 10 MW	64 MW
Number of wells	50	11
Drilling depth	2.100 meter	2.700 meter
Temperature from the ground	60 degrees C	77 degrees C
Period of drilling (days)	30	65

Tabel 7 - Comparison

Work has been focused on data collection in order to obtain proper and valid data for the new design. Data include: Investment costs, fixes and variable costs, lifetime of plant, project time span, construction period, rate of discount, capacity and efficiency of plant. Most of the data has been supplied by the other work packages.

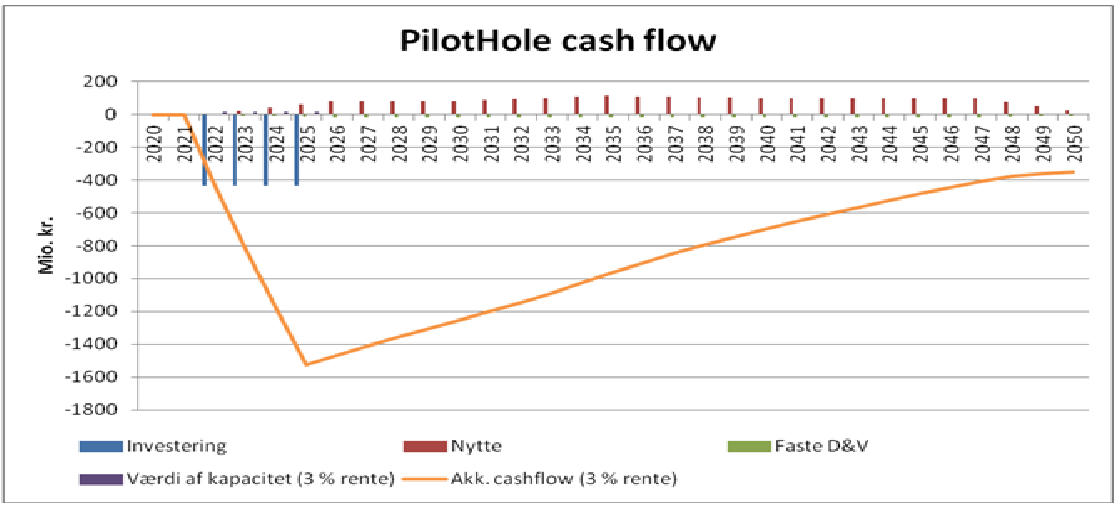
Methodology has been based on a cash-flow model previously developed by HOFOR and used for business case analysis for the Nordhavn geothermal project design in 2015.

A positive net present value of the cash flows indicates a sound business case.

Benefit of the geothermal production has been estimated by using the Balmorel model for the complete heat and power system of Copenhagen. The model minimizes the production costs in the entire production system for given heat and power demands. By comparing scenarios with and without the geothermal plants benefits of geothermal production can be estimated in terms of reduced total production cost. Benefits also take into account the capacity value of the geothermal plant.

Result of model analysis show a deficit in range 300-400 million DKK as shown in the figure below. This is an improvement of the business case of the Nordhavn design which shown a deficit of 700 million DKK for a smaller production capacity.

Total heat production costs of the new geothermal design are estimated to about 100 DKK per GJ as compared to about 120 DKK per GJ for the plant located in Nordhavn.



Figur 5 – Cash Flow

Conclusion of the work is that by now it is too expensive to make investments in geothermal heat plants as compared to alternative heat producing technologies available to the HGS, e.g. technologies based on biomass and natural gas.

In order to make the business case attractive to potential investors further technological progress and cost reductions are needed or political initiatives targeting to improve the competitiveness of geothermal energy.

There is a need for further work on the business case for the new geothermal design before being able to make a decision to invest in new geothermal capacity. Further work remains in HGS to validate the data for the business case.

4 Preface to economy of scale and influence of ownership and financing

The comparison of old and new design of a geothermal plant as described above shows that based on the calculations made by HGS using their financial model with HGS ownership and a 25-year depreciation period, there is a gap of DKK 300-400 mill. to make it a profitable business case.

The key to closing the gap is industrialisation and economy of scale by going from standalone geothermal projects to serial geothermal projects where learnings, cutting cost through replication and by implementing whole cycle management are essential factors.

This EUDP project has focused on industrialization and economy of scale regarding the wells. The case is 100 MW, delivered as 10 x 10 MW plants on locations selected by HGS. The plants will be delivered sequentially.

There is still work to do on applying industrialization and economy of scale to the surface facilities, and it is expected that significant improvements will contribute to closing the biggest part of the gap together with applying a 30-year depreciation period.

It is essential to start thinking about geothermal energy as an industry. Today's business model is standalone projects managed by the district heating companies who are not able to mitigate the risks associated with a drilling project.

It is all about letting a professional partner, who has the required expertise and technical capacity, take the risk. The future business model applying industrialization and economy of scale is one where

- a professional partner, i.e. Geoop, takes the risk on drilling the wells, and fulfils the operator obligations according to the Danish Subsoil Act.
- a professional partner within surface facilities takes the risk on the surface plant (optional – the district heating company may decide to take the risk – case 4 below)
- the district heating company, HGS, makes a commitment to acquire an agreed share of the wells when they work
- the district heating company, HGS, makes a commitment to acquire an agreed share of the surface facility when it works (optional – see above)
- and the district heating company, HGS, subscribes to 10 MW per plant whether they use the heat or not. It is Geoop's commitment and risk that the wells produce 10 MW, and the cost associated with delivering the 10 MW shall be covered by a subscription fee

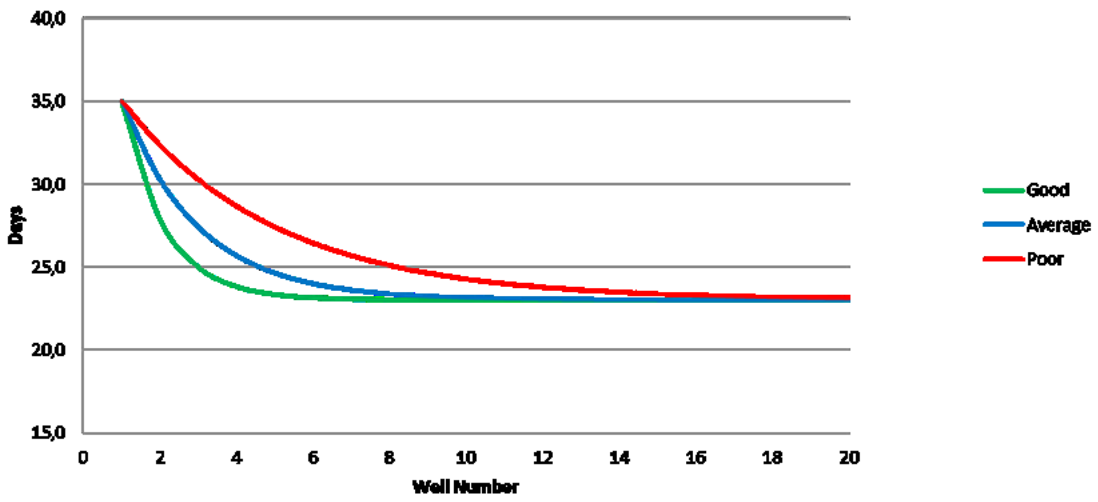
Other matters of influence to applying geothermal energy to district heating is of course taxes and legislative regulations, e.g. the Danish Heat Act. The current taxation is leading the district heating companies to prefer for instance biomass.

4.1 Analysis of economy of scale

Economy of scale is a significant factor for driving down cost. This is well known. It has been proved by the shale-gas industry and has resulted in savings of up to 52%. The same trend will be seen when i.e. 10 geothermal projects are planned and executed.

We off-set our analysis in the work done by Brett & Millheim and presented in their paper "The Drilling Performance Curve: A Yardstick for Judging Drilling Performance[1]".

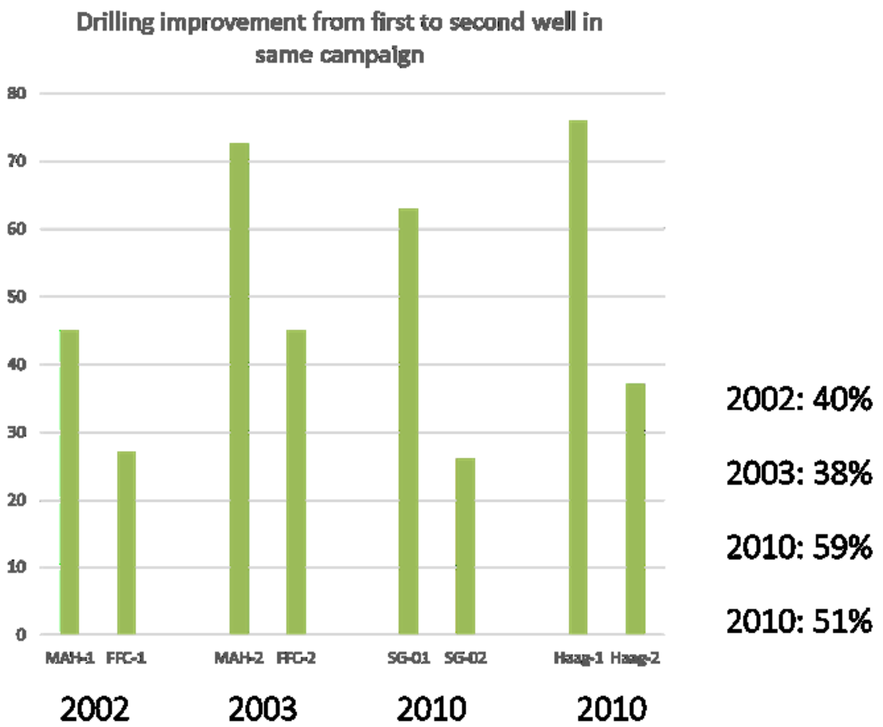
Their work looked at assessing with empirical data how performance gains are made.



Figur 6 – Brett & Millheim

They derived that performance can be improved by an average of 32% when working with the same boundary conditions; same rig types, same basin / reservoir etc.

Looking at drilling campaigns executed in the “old” geothermal model (one project with 2 wells, one district heating company, no professional partner) there were significant improvements from the first to the second well.



Figur 7 – Drilling improvement

With this study Ross applied the same metrics to the geothermal wells that we have been involved in and which had similar conditions of uniformity. This resulted in an average gain in efficiency of 47%. These empirical data indicate how rapidly efficiency gains can be made, and indicate that economy of scale considerations are very relevant when looking at unit costs per well, facility etc and how keeping momentum within a drilling campaign will ensure continuity in planning, execution, and testing.

An additional conclusion can be made: had the FFC-1 been drilled first, there would have been a saving of approx. 30% on MAH-1. The same applies to MAH-2 if FFC-2 had been drilled first.

4.2 Influence of ownership and financing

Geothermal energy is a resource and can be categorised alongside extraction of other natural resources – both green and less green. The value of the resource can be categorised differently, however, geothermal energy can be viewed as a commodity and a raw material. Using this outlook geothermal energy can be traded commercially with an exchange point in the heat exchanger between the geothermal brine and the direct heating flow loop.

Geothermal plants are infrastructure and attractive to investors with focus on long investments.

Ownership and financing go hand-in-hand with risk. The baseline is that

- a professional partner, i.e. Geoop, takes the risk on drilling the wells. A professional partner like Geoop would do this because they know how to mitigate the risk
- the district heating company, HGS, makes a commitment to acquire an agreed share of the wells when they work
- the district heating company subscribes to 10 MW per plant whether they use the heat or not. It is Geoop's risk that the wells produce 10 MW
- the shared ownership when the wells work and produce as committed combined with external financing and Kommunekredit financing make the business case profitable and dynamic

The table below illustrates 5 different cases with different ownership models and risk profiles – from case 1 where Geoop owns all assets to case 5 where HGS owns all assets.

This EUDP project has focused on case 4 where Geoop takes the risk on the wells and HGS owns the surface plant. With this case an amount of DKK 20-30 mill. per year is earned due to industrialisation and cheap financing as return on investment despite the fact that the external financing is more expensive than the financing coming from Kommunekredit and without influencing the heat price for the consumers. Case 3 could be an attractive alternative for the district heating company who would like to have an industry partner take the risk on the surface facility.

		HGS Investment (mill DKK)	Annual production garantee fee (mill DKK/year)	CAPEX (mill DKK/year)	CAPEX (DKK/MWh)
Case 1	All assets own by Geoop, Heat sold on 25 year contract MW pr MW	0	0	98	196
Case 2	Wells owned by Geoop, surface plant DH, 25 year contract	700	8	96	191
Case 3	Assets owned 30 % by Geoop and 70 % DH, 25 year contract	1217	28,5	95	191
Case 4	Wells owned 30 % by Geoop and 70 % DH, surface plant DH, 25 year contract	1427	17	95	191
Case 5	All assets owned by HGS	1738	0	96	191
	Wells	1038	mill DKK		
	Surface facility	700	mill DKK		
	Facility size	100	MW		

Tabel 8 – Investment scenarios

Finally, HGS has looked at the Net Present Value (NPV) and based on the figures it can be concluded that the project is viable with an investment horizon over 30 years, i.e. the DKK 300-400 mill. gap is closed. Furthermore, looking at levies of electricity for production will decrease the investment horizon to 25 year or significant strengthen the investment case on a 30 year horizon.