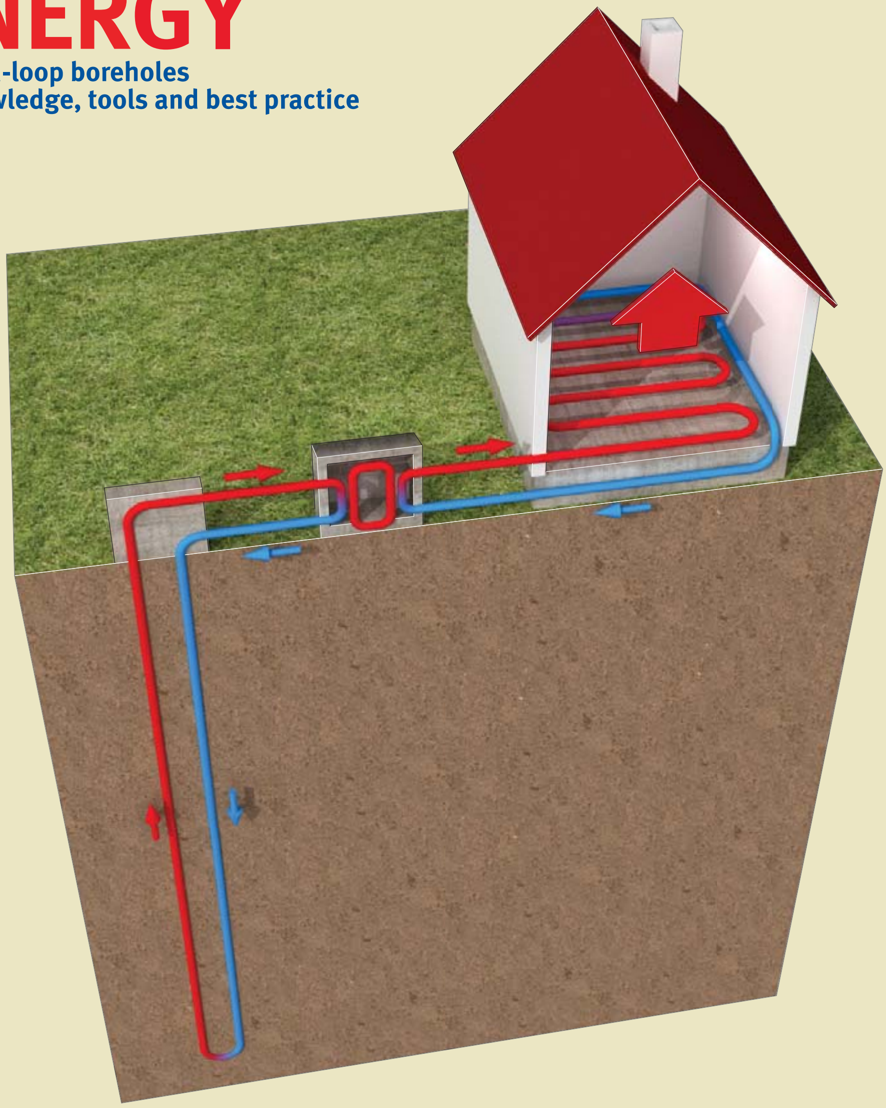
GEOENERGY
Closed-loop boreholes
– knowledge, tools and best practice



Tools for ground source heating and cooling based on closed loop boreholes

Energiteknologisk Udviklings- og Demonstrations Program (EUDP)
Theme: Energieffektivisering
Programme: EUDP 10-II
J.no.: 64011-0003

D1 Knowledge sharing workshop

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1 INTRODUCTION

Heat-pump systems based on closed-loop, geothermal boreholes, has a potential for CO_2 reduction and energy efficiency. The application in Denmark, however, is limited compared to our neighbouring countries and we still lack know-how and experience. The objective of the project “GeoEnergy, Tools for ground-source heating and cooling based on closed-loop boreholes” is to pave the way for a wider use of the technology by acquiring know-how and developing tools and best practice for the design and installation of plants as well as providing training and dissemination.

The project is co-financed by the partners and the EUDP programme of the Danish Energy Agency (Energistyrelsen) and the duration is 3 years starting from 2011-03-11. The partners are:

- De Nationale Geologiske Undersøgelser for Danmark og Grønland (GEUS)
- VIA University College, Horsens (VIA UC)
- Geologisk Institut, Aarhus Universitet (GIAU)
- Den Jydske Håndværkerskole (DjH)
- Dansk Miljø- & Energistyring A/S (DME)
- GeoDrilling A/S (GeoD)
- Brædstrup Fjernvarme AMBA (BrFj)
- DONG Energy Power A/S (DONG)
- Robert Bosch A/S IVT Naturvarme (BOSCH)

The work in GeoEnergy is structured in 8 work packages:

- WP1 Database and dissemination
- WP2 Equipment and measurements
- WP3 Temperature gradients and surface temperatures
- WP4 Drilling methods and grout techniques
- WP5 System design and energy balance
- WP6 Training and education
- WP7 Interaction with ambient groundwater system
- WP8 Guidelines and final dissemination

This document is deliverable “D1 Knowledge sharing workshop” of WP1 Database and dissemination. The report contains a summary of a knowledge sharing workshop hosted by VIA UC and with participation of international and national experts and the project partners. The purpose of the workshop was to identify, discuss and share knowledge about parameters relevant for the design of closed loop boreholes. The workshop was organized in 5 sessions and also included visits to local installations of ground source heat pump systems based on closed loop boreholes.

Each session started with an introduction by a selected speaker, identifying trends, problems and concerns within the topic. Hereafter followed a discussion aiming at exchanging experiences and with room for presentations from the invited international experts. In this document we outline the conclusions from the discussions in each session, including suggestions for relevant project activities and investigations.

2 PROGRAMME

Below is given an outline of the workshop programme:

Wednesday September 7th, room B 204

09.30 – 10.00	Arrival and coffee
10.00 – 10.45	Welcome and presentation of participants (Inga Sørensen) *The presentation will include a short status of the use of shallow geothermal energy in the countries represented by the participants*
10.45 – 11.00	GeoEnergy - "Tools for ground source heating and cooling based on closed loop boreholes", presentation of project and work programme (Henrik Bjørn)
11.00 – 12.30	**Session 1**: Soil types and measurement of geothermal properties (Chair: Claus Ditlefsen)
12.30 – 13.30	Lunch
13.30 – 14.00	Short visit in VIA UC's Geo-lab and coming energy laboratory
14.00– 15.30	**Session 2**: Energy demand versus system design and documentation of energy uptake (Chair: Inga Sørensen)
15.45	Departure for excursion *Visit to a ground source heating plant in Glud with closed loop boreholes, heat pump and instrumentation for monitoring energy uptake* *Other sustainable energy plants in the area including a domestic windmill, air–water heat pump, solar cells and horizontal ground source heating*
19.00	Dinner at Snaptun Færgekro

Thursday September 8th, room 6.01 in VBI Park

9.00 – 10.30	**Session 3** Drilling and grouting methods and environmental aspects (Chair Henrik Bjørn)
10.45 - 12.00	**Session 4** Brine and pipes – including relevant QC-activities during installation (Chair Morten Kjærgaard) *Visit to VIA UC's test plant with closed loop boreholes and temperature sensors*
12.30 – 13.30	Lunch
13.30 – 15.00	**Session 5** Modelling of heat flow - status and suggestions (Chair Anker Lajer Højberg)
15.00 – 15.30	Workshop summary

3 PARTICIPANTS AND SHORT COUNTRY STATUS

Below the workshop participants are listed:

International experts
Burkhard Sanner, European Geothermal Energy Council (EGEC)
Reinhard Kirsch, Landesamt für Landwirtschaft, Umwelt und Ländliche Räume, Schleswig-Holstein, Germany
David Banks, HolyMoor Concultancy Ltd., United Kingdom
Walter J. Eugster, Polydynamics Engineering Zürich, Switzerland
Benjamin Andersson, SWECO, Sweden
Jonas Ekestubbe, SWECO, Sweden

Project participants and national experts
Inga Sørensen, VIA UC
Henrik Bjørn, VIA UC
Lotte Thøgersen, VIA UC
Claus Ditlefsen, GEUS
Anker Lajer Højberg, GEUS
Richard Thomsen, GEUS
Niels Balling, GIAU
Schneider Philipsen, DME
Ib Bæk Jensen, DjH
Christian Christiansen, Foreningen af Danske Brøndborere
Per Dam, YIT
Niels Peter Skov, Varmepumpefabrikantforeningen
Morten Kjærgaard, GEO
Svend Vinther Pedersen, Varmepumpeordningen
Tillie Malene Madsen, Rambøll
Jette Sørensen, Rambøll

3.1 International experts and short country status

Below is given brief details on the international experts and a short status of the application of shallow geothermal energy in their respective countries:

Germany
Burkhard Sanner is, among numerous other activities, president of the European Geothermal Energy Council (EGEC) and vice chairman of the Guideline Committee "VDI 4640 Thermal Use of the Underground" of the German Association of Engineers and has been participating in the GeoTrainet project supported by Intelligent Energy Europe.

Reinhard Kirsch has many years of experience with geothermal energy and is co-author on a comprehensive report describing the geothermal potential in Schleswig-Holstein.

In Germany some 200.000 shallow ground source heat systems have been established and at present the market is moderate and fluctuating.

In Schleswig-Holstein there are about 4200 boreholes serving as ground heat exchangers and about 400 new boreholes are being drilled per year. There is a need for more work on groundwater protection in connection with closed loop boreholes and more information on the thermal properties of different sediment types is also needed.

On EU level a number of large shallow geothermal energy plants are being planned in e.g. Eastern European countries like Romania and Turkey.

United Kingdom
David Banks is the author of the textbook "An Introduction to Thermogeology: Ground Source Heating and Cooling" and has many years of experience in feasibility studies and design of ground source heating and cooling systems.

In the UK at least 10,000 shallow ground source heat systems are installed (closed loop vertical and horizontal systems and a minority of open loop systems). Recently there has been some negative press about the efficiency of boreholes: "Dirty" coal based electricity requires high efficiency GSH plants to reduce carbon emissions. Planned subsidy programmes have been postponed.

Switzerland
Walter J. Eugster has many years of experience as a consultant in the field of Borehole Heat Exchangers and is an expert in quality control during drilling and installation.

In Switzerland there are 2.5 million borehole meters of short geothermal boreholes and the market is expanding. There are many well experienced companies, but Q.A. can sometimes be a problem.

Sweden
Benjamin Andersson is a hydrogeologist and has been working with shallow geothermal energy for more than 10 years.

Jonas Ekestubbe has many years of practical experience from installation of closed loop borehole systems.

The market is still growing in Sweden. Focus is on smaller plants and there are guidelines for implementation. Central heating companies have a monopoly in urban areas and in the future it will be important to collaborate with them and not compete.

4 SESSION 1: SOIL TYPES AND MEASUREMENT OF GEOTHERMAL PROPERTIES

4.1 Initial questions

- What relevant table values exist for thermal properties of soil types and how were they measured
- Do we need more measurements with reference to Danish geology
- What soil types are important to distinguish between when estimating energy output from closed loop boreholes
- How do we best measure geothermal properties in the laboratory and in the field
- How do we obtain realistic water contents during measurements
- What do we know about the geothermal gradients in Denmark and what is the order of magnitude of the heat flux

4.2 Significant conclusions and comments from discussion

A review of geothermal gradients in Denmark and some interpretations on near surface variations was given by Niels Balling, GeoScience, University of Aarhus. Gradients of 1 to 3 degrees per 100 m are found. No considerable regional difference in thermal gradient is expected.

Variations in the near surface temperature gradient of closely spaced boreholes may be an effect of the actual location relative to buildings or other infrastructural elements.

Some databases exist with measurements of geothermal properties of rocks and sediments.

The New 2010 edition of the German VDI standard (4640 Blatt 1) gives updated recommended values of geothermal properties for soil and rocks.

Considerable difference between horizontal and vertical thermal conductivity has been measured in the laboratory.

Heat conductance measurements of soil samples in the laboratory can be problematic, as it is difficult to obtain the same conditions as when the sample was in situ and undisturbed. Hukseflux thin needle equipment is best in homogeneous, soft, fine grained sediments.

Development of equipment for field measurements of thermal conductivity may be relevant for dimensioning horizontal systems.

Examples of measurements on till and other sediments from Schleswig-Holstein was presented.

When measuring thermal conductivity it is important to best possible ensure constant measuring conditions, and when evaluating measurements it is important to differentiate between scatter from varying measuring conditions and scatter due to variations within specific geological formations.

Thermal response testing may offer a better way to evaluate expected energy uptake from specific boreholes. A review of advantages, cautions and disadvantages of thermal response test in boreholes were given based on Geotrainet material.

4.3 Available presentations from session 1

Claus Ditlefsen: Workshop session 1
Danish geological framework and division of Danish rocks and soils into 12 types. Jupiter database and standard for sediment description.

Niels Balling: Temperature and heat flux
Key figures for intervals of temperature gradients, thermal conductivities and heat flux, examples of measurements of temperature gradients.

David Banks: SoliHeat – Thermal Needle Probe
Thermal probe inserted directly into auger excavations or base of trial pits – for horizontal ground source heat systems.

Reinhard Kirsch: Geothermal energy use, Sleswig-Holstein
Geological overview of the region, interpolation of thermal conductivities from drilling results, use of geophysical measurements for preparing maps showing regional geothermal properties, approach to grouting control.

Burkhard Sanner (Marc Sauer): Performance of thermal response test
Geotrainet course material on thermal response testing by Marc Sauer, presented here by Burkhard Sanner.

5 SESSION 2: ENERGY DEMAND VERSUS SYSTEM DESIGN AND DOCUMENTATION OF ENERGY UPTAKE

5.1 Initial questions

- Are there specific issues related to the energy demand of buildings
- How do we calculate the thermal load and analyse the energy demand
- How do we avoid misunderstandings between owners/architects and designers
- How can we measure the energy-uptake in the ground
- What instruments should we use to measure flow speed and temperature of the brines
- How do we find/measure density and heat capacity of different brines
- Are there any help to get in the German VDI norms
- How do we best test the entire system design and what should be measured

5.2 Significant conclusions and comments from discussion

The energy demand for new houses can be calculated from known U-values for the different components of the building. This may be quite difficult for old houses – here the best way is to find out how much energy the existing heating system delivers to the house (via gas meter, consumption of oil etc.). However, when using existing energy consumption for the dimensioning of a future ground source heating system one should be aware of the insulation status of the house. Sometimes the energy demand can be significantly reduced just by improving the insulation of the house.

Over-dimensioning of ground source heat systems should be avoided – this is not a problem e.g. for oil boilers, but an oversized heat pump will mean more wear on the compressor because of many start and stops.

To calculate the energy uptake from the ground we need to know the heat capacity of the brine, Δt and the flow velocity of the brine. Danish brine is often 1/3 IPA-alcohol mixed with 2/3 of water. IPA-alcohol is a mixture of Ethanol (85-95%) and Isopropanol (5-15%). The international experts at the workshop were not familiar with this type of brine – apparently clean Ethanol or Propylene glycol is normally used in other countries.

The flow velocity of the brine can be measured using ultrasonic flow meters or magnetic induction flow meters. The accuracy of the ultrasonic method is quite good but the equipment needs to be calibrated against the fluid density.

The heat capacity of most types of brine can be found as table values, but dependency of the temperature may not be reflected/considered in the tables. However, the normal temperature interval for brines in a ground source heat system is relatively narrow (from around 11-15 degrees Celsius to a few minus degrees Celsius), and the effect of known temperature dependencies can be incorporated in the calculation of the energy.

Reference was given to a book written by Åke Melinder: “Thermophysical properties of aqueous solutions used as secondary working fluids”. The book is from 2007 and published by “Kungliga Tekniska högskolan” (Royal Institute of Technology) in Stockholm.

In Denmark some installers use, as a rule-of-thumb, that the brine should be frostproof down to minus 18 degree Celsius. This is not relevant for vertical closed loop systems – only for horizontal closed loop systems located 1-2 metre below ground surface.

Air in the system must be removed. This is often a challenge – especially when the brine is glycol because this liquid has a tendency to build up foam.

Systems with integrated energy absorbers connected to the circulating brine were discussed. These systems were introduced in the 1980's. The energy absorber could be very simple – e.g. a grid of black pipes placed on a flat roof. The idea is to store heat in the ground. A student project at VIA UC will try to test the back of solar cells as energy absorber – the idea is that the brine can cool the solar cells and make them more efficient and transfer the absorbed heat to the ground.

The distance between individual closed loop boreholes in an array were discussed. There seems to be no good arguments for the Danish rule requiring at least 20 metres between adjacent closed loop boreholes.

A good overview of the entire system design can be difficult because of the many partners involved such as driller, supplier of heat pump, installer and electrician as well as the plant owner.

To monitor a ground source heat plant, you first of all need an overview diagram of the installation and information about which components are relevant to monitor and then a list of possible equipment for the desired measurements.

PLC (Programmable Logic Controller) was explained and it was stressed how important it is to use standard components when setting up the system.

Components monitor could be (included in the PLC in Glud): temperature of ingoing and outgoing brine, outdoor temperature, flow velocity of brine, pressure in brine circuit, electricity consumption for the heat pump (including compressor + circulating pump for the brine), energy delivered to the house, energy used for the resistance heater (the back up heater for cold days). Based on the above measurements other parameters can be calculated – such an energy uptake from the ground, COP for the heat pump etc.

5.3 Available presentations from session 1

Inga Sørensen: Workshop session 2
Energy demand versus system design and documentation of energy uptake.

6 SESSION 3: DRILLING METHODS AND GROUTING, INCLUDING ENVIRONMENTAL ASPECTS

6.1 Initial questions

- What drilling methods will work in soft sediments
- Will casing always be necessary during drilling
- How deep can/must we drill
- How much shrinkage/settling of the injected grout should be expected
- What method for grout mixing prior to injection should be used

6.2 Significant conclusions and comments from discussion

Regarding drilling methods it was rapidly concluded, that drilling in soft sediments implies much larger challenges than drilling in hard rock.

Direct rotary mud drilling was generally seen as the most efficient method in relation to speed, cost and quality of borehole.

Warnings were given against drilling in soft sediments without casing. It will result in cavities, collapsing boreholes, damage to Borehole Heat Exchangers (BHE), enlarged diameter of borehole and need for more grout.

Warnings were also given against drilling deeper than 100 meters in soft sediments. The possible problems with e.g. sealing and grouting and installation of BHE's, increases dramatically with depth.

A poorly constructed borehole will have a very short lifetime.

The Danish rule requiring at least 20 metres between adjacent closed loop boreholes is only relevant in connection with neighbouring plants. Within individual plant systems, a distance of 6-8 metres between boreholes will be sufficient in most cases.

Grout should always be thermally enhanced and ready-mixed products from recognized manufacturers should be used. It is too complicated to try and mix it yourself.

The packing of the grout in the borehole can be improved, if spacers are used on the BHE's.

Grout should be mixed in batches (using two batch containers/mixing vessels) in order to secure the correct ratio between dry-matter and water. Too much water will result in very large settling time. Too thick grout may clog the grouting pipe.

A shrinking of 1-2 percent should be expected. Refill from top.

Experiments with freezing and thawing of grout have been carried out in Germany and there seems to be a problem with exfoliation of the grout. Similar observations are known from Austria. This can increase the permeability of the grout and the problem seems to increase if freezing/thawing occurs immediately after grouting. It is recommended to avoid frost for 40 days after hardening of the grout.

6.3 Available presentations from session 1

Henrik Bjørn: Workshop session 3
Drilling and grouting: various drilling techniques, their advantages and disadvantages, different grout types.

Burkhard Sanner: Geology and environmental issues
Material from Geotrainet Drillers course.

7 SESSION 4: BRINE AND PIPES INCLUDING RELEVANT QC-ACTIVITIES DURING INSTALLATION

7.1 Initial questions

- What pipe materials can be used and what are their thermal properties and lifetime
- What are the advantages and disadvantages of different types of U-pipes
- What are the advantages and disadvantages of different types of brines – toxicity
- Which QC procedures are relevant during installation

7.2 Significant conclusions and comments from discussion

In general there was consensus at the workshop (except from a couple of protests) that the environmental risks connected to closed loop boreholes are low. Only one case story with leakage from closed loop boreholes could be identified by the assembled experts, being a case story from Birmingham, with leakage in Sherwood Sandstone.

The toxicity of the brines is generally low, but mono-ethylene glycol is regarded as undesired in the UK due to a higher toxicity, than the alternatives.

IPA-alcohol (frequently used in Denmark) was unknown to the international participants.

7.3 Available presentations from session 1

Morten Kjærgaard: Workshop session 4
Different types of pipes and brines, legislation on distance between boreholes and toxicity of brines.

8 SESSION 5: MODELLING OF HEAT FLOW

8.1 Initial questions

- How should we consider varying (hydro-)geology, i.e. varying thermal properties and flow velocities
- How should we consider near/far field heat transport
- How should we consider short term transport or local equilibrium
- How should we consider coupling between ground heat exchangers and surface installation to account for varying demand for heating/cooling
- What are the recommendations for software/tools

8.2 Significant conclusions and comments from discussion

David Banks presented experiences from modelling of GHE systems in two and three dimensions, with comparison to analytical solutions setup in excel spread sheets. A basic recognition from the study was that heat is transported at a velocity slower than that of pure advective transport, i.e. a retarded velocity. Retardation is caused by the interaction between heat in the aqueous and solid phases, a process similar to sorption of chemical solutes. It was further found that 2 dimensional problems may be adequately described by analytical solutions. However, for aquifers imbedded in low permeable layers, such as a sandy aquifer confined upwards/downwards by clay layers, the study clearly demonstrated that heat transport travel distances may be significantly overestimated if the problem is considered a 2D and not a fully 3D problem. This is due to the conductive heat transport into the low permeable layers, which enhances the retardation of the heat transport.

General remarks
Modelling of GHE/BHE systems is well known and the literature provides numerous examples based on both analytical and numerical solutions. Much knowledge may be gained from the studies reported in the literature, but the participants also acknowledge that it may be necessary to draw own experiences based on modelling, and inclusion of modelling in the GeoEnergy project was encouraged.

From some of the workshop participants it was recommended that modelling of GHE systems in practise should only be considered for design of large systems. Small systems for individual users should be based on experiences/look-up tables, since it would often be cheaper to dimension the system a little larger than to set up complex models for detailed design.

Input to modelling strategy
Based on the comments from the participants, the following conclusions are drawn:

- Effect of varying/heterogeneous hydrogeology and thermal properties may be relevant to study
- Effect of groundwater flow on the potential of GHE system has been quantified in earlier studies
- Assumption of local scale equilibrium may be ok for most design studies, as it is generally the long term impact that is of interest, i.e. the long term changes in the subsurface temperature. Short term dynamics may of course be relevant to consider for

designing specific systems with varying (daily and seasonally) heating/cooling requirements.
- Coupling of BHE and surface installations is complex and requires specific knowledge on the "in-house" installations. As a starting point, it was recommended to use a simplified input function for design criteria, such as criterion on minimum outflow temperature from the heat pump (inflow to the BHE) and a constant temperature change between in- and outflow temperature of the heat pump.

Tabulated values
David Banks informed about "The Microgeneration Certification Scheme" (http://www.microgenerationcertification.org/) with newly released standards for electricity and heat production based on renewable resources. The material includes recommendation on how to design GHE systems. Look-up tables are provided in which the maximum amount of energy that can be extracted (W/m) from vertical and horizontal GHE's is tabularised for different mean ground temperatures and average ground thermal conductivity. The look-up tables are calculated values based on model simulations, and physical/chemical properties for grout, pipes and brine has been specified, but the applied model code is not referenced. Design criteria for the model computation is similarly not provided explicitly, but is expected to follow the design criteria stated elsewhere in the material.

Similar look-up tables have been established for German conditions.

Model software systems
Several of the international participants had personal experience with Feflow, which was generally found adequate for simulation of BHE's. An apparent bug was, however, discovered when the brine was described by the physical properties of water.
Design of GHE systems in practice are generally not based on Feflow simulations but rely on computer models that requires less setup and calibration. Typical codes include:

- EED (Earth Energy Designer) which is the tool primarily used by SWECO
- GLD (Ground Loop Design)
- GLHEPRO which has a widespread use in US

8.3 Available presentations from session 5

Anker Lajer Højberg: Workshop session 5
Modelling of heatflow.

David Banks: Modelling of open loop systems
Modelling of GHE systems in 2D and 3D and comparison with analytical solutions.

9 CONCLUDING REMARKS

All the invited experts in the field of shallow geothermal energy contributed significantly to the workshop and the discussions were long and fruitful. The project has gained important knowledge from the experience of the international participants and the workshop is regarded a success. The invited experts found it very positive that an ambitious project like GeoEnergy could be carried out based on national funding. The workshop has also served as a tool to inform international colleagues about current activities in Denmark and has improved the level of networking between Danish and international experts considerably.