Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Geothermal Development in Denmark, Country Update WGC 2005.

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ABSTRACT

In the 1980's DONG drilled 4 deep geothermal wells in the Northwestern part of Denmark and erected a geothermal pilot plant in Thisted producing heat from a 45°C Gassum sandstone aquifer. However, empowered by the Danish government, the district heating energy industry focused on establishing combined heat and power plants. This helped to develop district-heating networks, but it left no demand for geothermal heat.

From mid 1990's the competitive power of geothermal heating started to increase, primarily due to the political focus on the use of non-CO_2 producing heating sources and an increased taxation on fossil fuels. Since WGC 2000, the level of geothermal activities has increased.

The plant in Thisted has continued to produce heat with low operating costs using absorption heat pumps and it was expanded to extract 7 MW from 200 m^3/h of the 15% saline geothermal water in 2001. Preparations for a demonstration plant in Copenhagen, to produce 14 MW heat from a 73 °C, 19% saline Bunter sandstone aquifer, were initiated same year. Production is expected to begin in November 2004.

An assessment of the potential for new plants in Denmark has been initiated. Based on this assessment DONG VE and the local district heating companies will be able to investigate the possibilities for an increased use of geothermal heat.

1. INTRODUCTION

This paper is about exploitation of geothermal heat from the interior of the earth and its use for district heating. Denmark has, however, also some heat production based on ground water and solar heat accumulated in the topsoil referred to in "3.1 Plants based on Ground Water and Topsoil." only.

Denmark has moderate temperature gradients, but widespread geothermal aquifers and district heating network. Two geothermal plants have been erected and several Danish towns have been identified with sufficient geothermal resources for hundreds of years heat supply.

The attitude of the Danish Government towards geothermal energy is positive, and the legal framework is in place. It is, however now up to the industry to prove that geothermal energy technically and economically is viable. No public funding is available for geothermal plants any more, but the high taxes on fuel for heating, and long periods with low sales prices for electricity from combined heat and power plants have made geothermal heat more attractive.

DONG VE holds licenses for under all major cities outside the Greater Copenhagen Area as well as it is partner in a license covering the underground of the Capital. The company is part owner and part operator of the two existing geothermal plants and intends also in the future to join partnership with interested district heating companies and other heat producers. DONG has furthermore, financed by Danish grants, provided assistance in designing, erection and operation of geothermal plants abroad in cooperation with Houe & Olsen and PGI.

DONG VE works closely together with GEUS (Geological Survey of Denmark and Greenland) concerning geological mapping and evaluation of reservoirs, and Houe & Olsen concerning surface facilities.

2. GEOLOGY BACKGROUND AND RESSOURCES

The geothermal production is and will be related to permeable sandstone layers. Diagenetic cementation generally increases with depth; setting a limitation of potential exploitable layers to depths above 2½ km. Maximum temperatures are at around 80 ^{o}C.

2.1 Structural Elements

The development of the underground of Denmark is dominated by some major structural elements (Figure 1) that significantly have influenced the depositing of reservoirs.

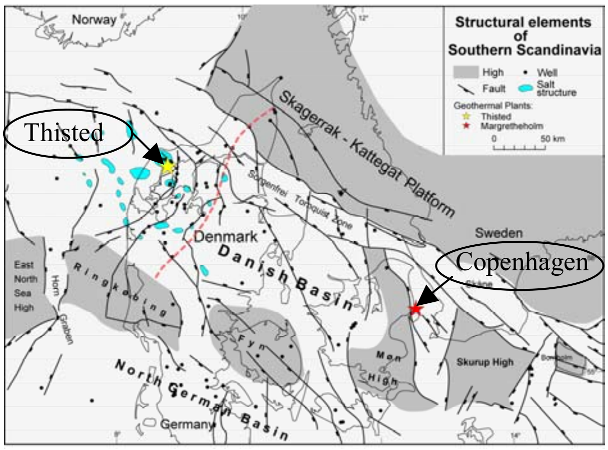


Figure 1: Map showing the well location and the principal structural elements; the Ringkøbing-Fyn High is based on deposition of Zechstein deposits. The dashed red line shows the position of the geosection in Fig 2. (Map from GEUS 2004).

Through geological time 4 sandstone reservoirs of major potential and 4 additional reservoirs of minor or more uncertain potential have been deposited sourced mainly from the Skagerrak-Kattegat Platform and Ringkøbing-Fyn High.

Most reservoirs are situated in The Danish Basin. Regionally of highest importance is The Gassum Formation, but locally The Frederikshavn Formation, The Haldager Formation and The Bunter Formation have god potentials.

Due to erosion reservoirs are nearly absent over the Ringkøbing-Fyn High. In the Danish part of The North German Basin the Bunter Formation is the most important reservoir.

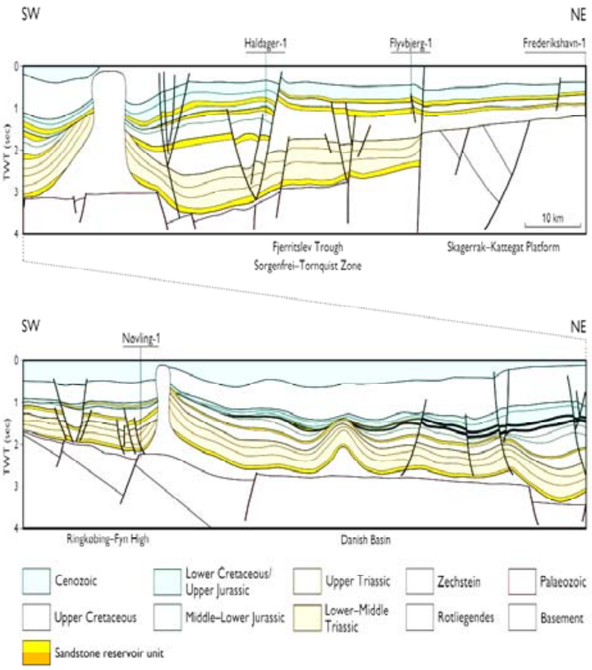


Figure 2: A regional SE-NE geosection in TWT (two-way travel time) through the Danish Basin and the Fennoscandian Border Zone. Notice the possible sandstone reservoir units. For location of the geosection, see Fig. 1. (GEUS, 2004).

The depths of the reservoirs vary considerably from area to area. The cross section Figure 2 illustrates this. This means, that general assessments are not very valuable, and it is necessary to perform local evaluations of every individual location to estimate the production potential.

2.2. Geothermal Resources

In general suitable reservoirs can be found under the major part of Danish cities and GEUS has identified sufficient geothermal resources to cover the heat demand in Denmark for hundreds of years.

Water chemistry is an important topic in evaluating the suitability of the reservoirs for long-term production to avoid precipitations clogging up the wells and/or surface installations. No problems have been experienced in the Gassum Formation, and so far Bunter Formation have produced satisfactorily.

Temperature wise Denmark is a low-enthalpy area with no pronounced temperature anomalies. The gradients have been investigated by Aarhus University. They depend on the composition and insulation characteristics of the different strata. The gradient tend to increase with depth with a total of 25 - 30 ^{o}C /km from surface to the total depth of a well.

As very rough rules of thump for geothermal aquifers:

- The temperature is at around 30°C per km dpth
- The salinity is at around 15 w% at 1.5 km's depth increasing with 10w% per km
- The permeability is at around 1 Darcy at 1.5 km's depth and halved each 300 m additional depth

3. GEOTHERMAL UTILISATION

Two plants are erected and in operation in Denmark. The Thisted Plant has been in operation since 1984, and the Margretheholm Plant has started its operation in autumn 2004. The locations are shown on figure 1.

Geothermal plants with absorption heat pumps can produce heat all year with typical heat to consumed electricity ratios at 6 - 20 depending on the aquifer and the operating conditions.

Furthermore such plants can, as demonstrated in earlier papers from Allan Mahler at WGC, when combined with a heat and power plant, supply heat and power flexibly or produce heat only with several hundred % efficiency measured from fuel to heat.

Heat production based on ground water and solar heat accumulated in the topsoil etc. has typical heat to consumed electricity ratios at 2.4 - 4 and such plants have been installed outside the district heating areas.

Around 65 person-years from professionals with an university degree and around USD 40 million, hereof approx. 90% private, has been invested in the use of geothermal heat for district heating within Denmark and in Danish paid assistance to projects abroad in year 2000-2004.

3.1 Plants based on Groundwater and Topsoil.

Approx. 250 groundwater based units and around 43.000 other heat pumps were installed ultimo 2004 extracting heat from air and solar heated earth through vertical buried pipes. Together they extract around 3900 TJ heat annually with an average system COP of approx. 3.0.

Some industrial cooling systems using groundwater have also been installed, but the Danish climate rarely call for geothermal cooling.

3.2 Geothermal plant in Thisted

A geothermal pilot plant transferring heat to the district heating network in Thisted from 35 m^3/h geothermal water through an electrically driven heat pump was erected by DONG in 1984.

The plant was enlarged to extract 4 MW from 150 m^3/h in 1988. This included exchanging the electric heat pump with an absorption heat pump primary driven by heat from a combined heat and power (CHP) incineration plant instead of costly electricity. All of the driving heat is transferred to the net, and the heat pump is driven by the difference in temperature level between the driving heat and the transferred heat.

This plant was described in great detail in earlier WGC papers from Allan Mahler. However, the plant was expanded to 7 MW in year 2000-2001 and considerations on how to use such a plant for heat storage could still also be of interest. Furthermore, the geothermal water properties and the design and operating strategy of the plant has made it possible to avoid corrosion problems and injection problems for the 15% saline geothermal water injected in sandstone since 1984. A brief description of the present plant is thus included in this paper.

3.1.1. Present Plant

The geothermal plant in Thisted pumps up to 200 m^3/h of 44°C warm geothermal water from a high permeable Gassum sandstone aquifer at 1250 m depth, filters the water, extracts the heat, pumps the water to an injection well 1.5 km from the production well, filters the water again to 1 micron and reinjects the water to the aquifer.

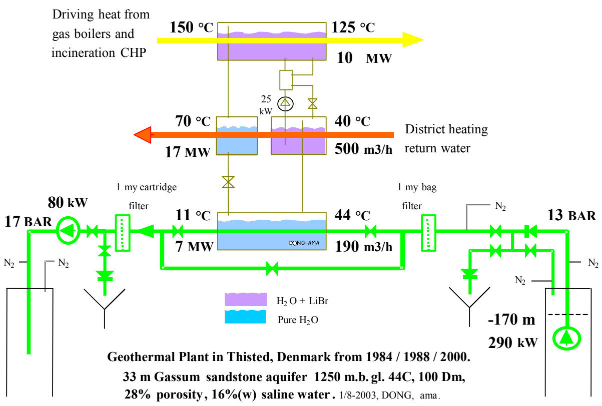


Figure 4: Simplified geothermal plant in Thisted with two absorption heat pumps in series shown as one.

Only one heat pump is shown above. In the actual configuration two heat pumps are installed with evaporators in series and (because of capacity restraints) both absorbers and condensers in parallel. Furthermore a small heat exchanger is installed between the evaporators to increase the production of condensation heat from the peak load gas boiler installed in the plant.

DONG VE owns the geothermal loop comprising wells and surface facilities containing geothermal water. DONG VE has also the responsibility for the operation of the geothermal loop, but the district heating company, TV takes care of the daily operation in accordance with DONG VE's instructions and TV owns and operates the heat pump plant and the district-heating network.

The corrosion rate in normal carbon steel exposed to the geothermal water has been measured to 0.06 mm per year, and the plant is designed with 3 mm corrosion allowance. The plant is protected towards air ingress into the saline geothermal water by nitrogen bottles maintaining an overpressure, when the plant is stopped, and furthermore by an operating system avoiding low pressures when the plant is operating and stopping.

The power to heat ratio (COP) for the geothermal plant in Thisted varies during normal operation between 5 and 25. It can become down to around 5 on max. load when including lost power production on the incineration CHP plant and using steam directly from the incineration boiler otherwise used for power production. It can also become 16-25 depending on the load when producing 7-4,5 MW heat using 0,4-0,2 MW power and driving heat from a peak load boiler or the incineration boiler in periods with spare steam production capacity.

The geothermal plant operates primary when it is cold and / or windy. In such periods with excess power production capacity, combined heat and power plants CHP) can convert heat production to power production with an unchanged fuel consumption and produce both heat and power with around 90% efficiency. The use of driving heat from the CHP may reduce its power production, but it creates no heat loss. Fuel savings when producing geothermal heat become then equal to the net energy production (heat production from the geothermal water minus power consumption) divided by 90%. If the geothermal plant in Thisted is assumed to have a net heat production of 6 MW substituting CHP heat production in this way during 3000 hours annually and to operate with about the same efficiency as alternative heat suppliers the remaining hours of the year, then around 65 TJ fuel and 5000 ton CO_2 can be saved annually assuming saved fuel to be oil.

The total investment costs are EUR 11 million including costs for the Pilot Plant and the deep explorative production well. The expansion of the plant in year 2000-2001 amounted to EUR 1.5 million including the new absorption heat pump, a new frequency controlled submersible pump, more filters and a frequency controlled injection pump.

3.2.2. Potential use for heat storage

Geothermal plants can be used to store heat and it has been considered to store excess heat from the combined heat and power incineration plant in the summer time. Compared to storage in ground water heat losses are substantially reduced as the geothermal water stays in place and loose little heat to the warm surrounding earth layers.

The heat can be stored by installing a submersible pump in the injection well pumping heated water into the production well. According to preliminary simulations such a concept could e.g. store 53 out of 63 available TJ during duration curve hour 5500 to 8760 and recover 23 TJ stored heat during hour 0-1000.

A more efficient concept is, however, to use an additional well allowing storage and production when wanted. Compared to the two well concept more heat can be stored with smaller losses - and more stored heat can be produced when needed. Preliminary simulations indicate the three well concept e.g. can store 59 out of 63 available TJ during duration curve hour 5500 to 8760 and recover 50 TJ stored heat during hour 0-2750.

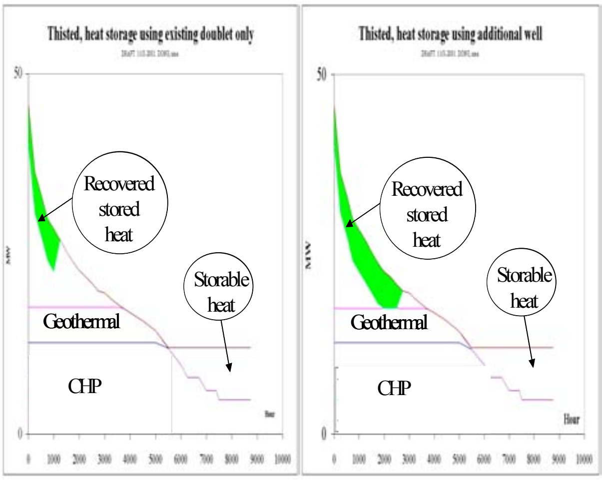


Figure 5: Simple heat storage concept with submersible pump installed in present injection well.

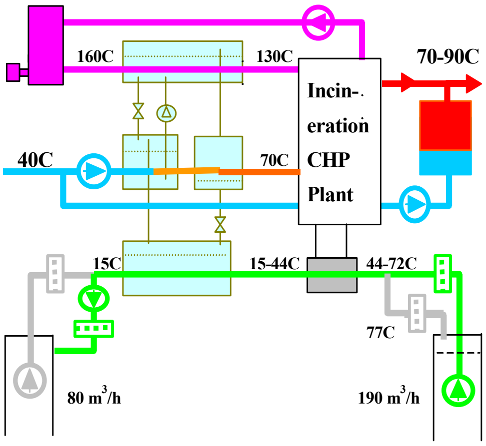


Figure 6: Simple heat storage concept with submersible pump installed in present injection well.

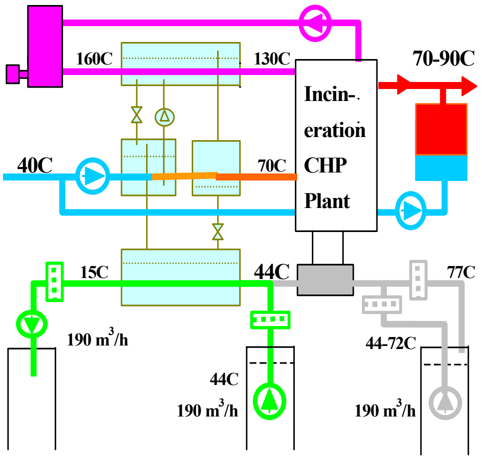


Figure 7: Heat storage concept with additional well for storage and heat recovery.

3.3 Geothermal plant in Copenhagen

In 1999 DONG VE formed a group (HGS) with heat and power producers and district heat transmission companies to introduce geothermal heat in the Greater Copenhagen Area, where the largest district-heating network is situated.

Figure 8: Geothermal plant in Copenhagen

HGS was granted an exploration and production license 2001, and at the same time 83 km seismic survey on land and 231 km at see were performed. The results were encouraging as geothermal reservoirs could be expected nearly everywhere in the area.

A locality near the Amager Combined Heat and Power Plant (CHP) was chosen to obtain easy access to driving heat for absorption heat pumps and to be able to test wells producing water directly to the sea. The first well, Margretheholm-1, was drilled vertically to the basement situated in 2,7 km's depth during the summer 2002.

Tests and evaluations showed, that the Bunter Formation at 2,5 km's depth could be produced at acceptable rates with a productivity of around 8 m^3/h per bar, and a second well, was drilled 10 m from the first well in the summer 2003. This well was deviated to a step-out of 1,3 km and tested to a productivity of around 6 m^3/h per bar and a good communication to the first well.

In the autumn 2003 it was thus decided to build a plant to extract 14 MW heat from 235 m^3/h of the 73°C, 19% saline geothermal water with DONG VE as operator for the geothermal loop and Energi E2 owning the Amager CHP as operator for the heat pump plant.

The heat pump plant with 3 absorption heat pumps in series is located close to the supply of driving heat from the Amager CHP approx. 800 m from the geothermal loop plant next to the wells.

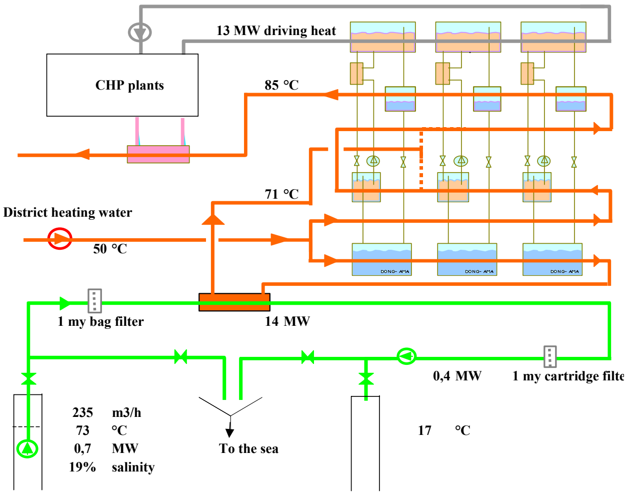


Figure 9: Geothermal plant in Copenhagen extracting heat using heat exchangers and absorption heat pumps.

The geothermal water in the Copenhagen plant has a higher CO$_2$ content and salinity than in Thisted. The geothermal loop is thus, apart from the use of a deviated well instead of an injection pipeline, designed with:

- Carbon steel piping with 5 mm corrosion allowance

- AISI 316 filter houses with corrosion protection rods

- Option for automatic manipulating of valves.

- Titanium plate heat exchanger separating geothermal loop

The geothermal water is brought to the surface at 10-15 bar by a 650 kW submersible pump, filtered to 3 micron absolute rating in bag filters, passing through the heat exchanger being cooled to 17 °C, filtered to 3 micron absolute rating cartridge filters and reinjected to the aquifer at 50 bar wellhead pressure using a 450 kW injection pump.

The plant shall produce 14 MW and 380 TJ heat annually from the geothermal water. The 380 TJ annually equals the early consumption of 5.800 dwellings or a bit more than 1% of the total production to the network.

The annual reduction of CO_2 emissions can be assessed to around 10.000 ton based on considerations similar to those mentioned for the Thisted plant, however, with driving heat supply from turbine outlet on coal-based plant.

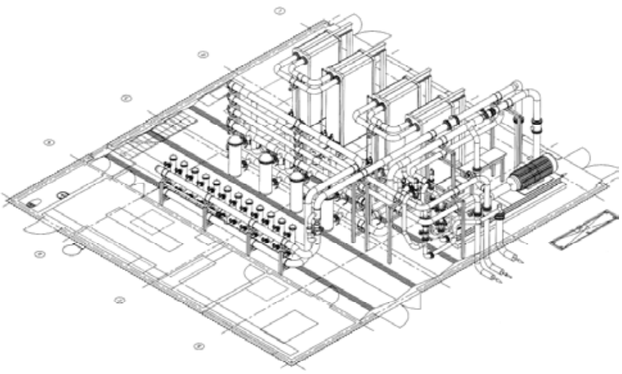


Figure 10: Geothermal loop in building

The 14 MW is extracted cooling the geothermal water from 73 °C to 17 °C. The 13 MW heat from the Amager CHP used to drive the 3 absorption heat pumps is also transferred to the district heating network to total 27 MW.

The total investment incl. seismic surveys amounts to 25 million ECU.

4. FUTURE DEVELOPMENT POTENTIAL

The establishment of new plants depends on the existence of local suitable sandstone reservoirs. Such aquifers can as mentioned in the above be found under most Danish cities.

To be competitive a minimum size of the market is needed. Also it is important that the legal framework supports and eases the establishing of geothermal production. Furthermore operating conditions such as temperature level and options for supply of driving heat are important.

Calculation of the heat production costs requires simulation of the operating conditions through a year and computer programs has been developed to calculate pressure levels, energy balances and heat production costs optimising design and operation considering while respecting constraints on the heat supply and changing district heating temperature levels. An example of a calculation of the heat production costs using a screening program based on very few input parameters is included as the last figure.

4.1 The market potential

An obligation to produce heat on combined heat and power plants where possible has been softened and the competitive power of geothermal heat has been improved due to increased taxes on fuel for heating and the concern for future fossil energy prices considering the recent rises, the increasing world demand, the associated environmental problems and the suitability for green taxes.

Central heat production costs for big networks with primary heat supply from coal based combined heat and power plants have recently experienced around 40 % increased prices. The higher cost level on other networks has increased less.

The higher taxes on fuels for heating has been facilitated by the acceptance of green taxes and the financial opportunity created when a big part of the loans financing the district heating networks was repaid.

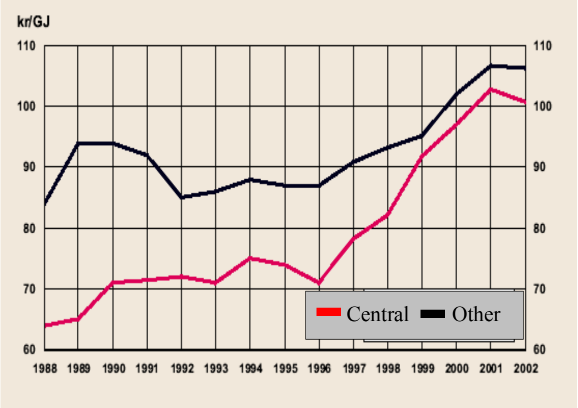


Figure11: Average production prices for district heating

Experience and resent studies indicate competitive geothermal production prices typically at around 7 - 11 EUR/GJ (one EUR = 7.5 DKK). However, prices for the existing heat production vary a lot between networks and the individual heat producers to the same network, typically in the range of 6 - 16 EUR/GJ. Detailed investigations performed together with the local district heating companies are thus required to reveal the potential.

The geothermal heat production price dependency on the heat demand starts normally to flatten at around 500 TJ annually rarely reaching an acceptable level below 250 TJ annually. When combining the need of a suitable underground and a market not less than 250 TJ/year, a range of approximately 20 localities could have potential for geothermal heating.

4.2 The legal framework

The sale of heat to district heating systems is regulated to protect the customers against the otherwise very strong position the limited number of local producers could have on local price setting. Generally the price is thus only allowed to include certain well defined elements as pay back of normal loans to necessary investments in plants, purchase of fuels, maintenance.

To ease the risk associated investments in geothermal plants, the regulations, however, allow for a surplus to be added into the price, thereby opening up for private industry investments. The surplus shall cover the increased risk level, primary the exploration risk. However an independent board, Energitilsynet, shall approve the prices and has at any time the power to change the price.

Exploration and production of geothermal energy requires a concession granted by the Energy Agency who also shall approve the final plant together with the local authorities.

5. FUTURE DEVELOPMENT AND INSTALLATIONS

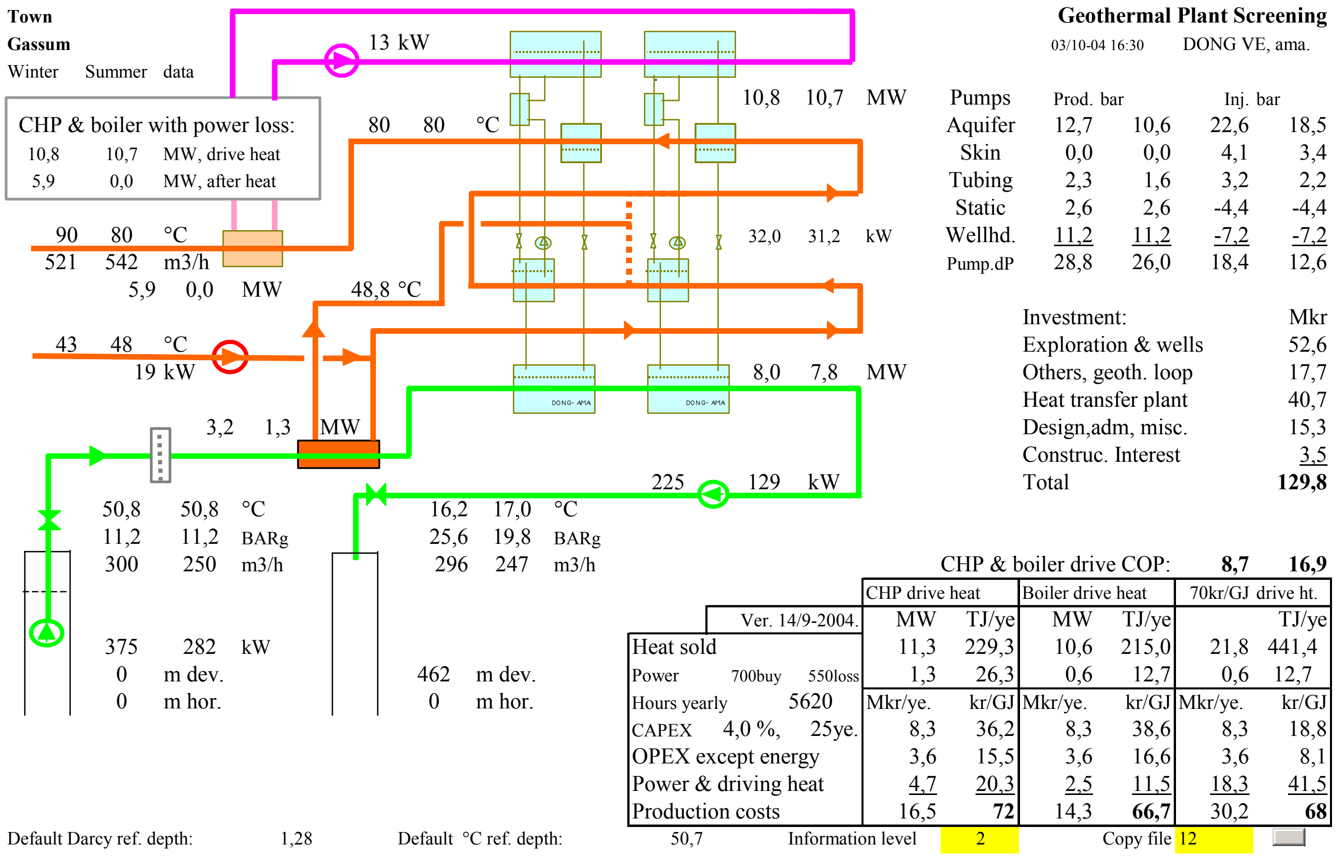
During autumn 2003 and spring 2004 GEUS and DONG VE have reevaluated the geological potential in Denmark. Further DONG VE has evaluated the economical feasibility in relation to a number of cities and discussions are now taking place with potential customers.

The business concept is co-ownership between the local district heating company and DONG VE with the local district heating company as operator of the heat pump plant and DONG VE as operator for the geothermal water production. The district heating company pays all operating costs and repays DONG VE's investments with interest. DONG VE offer, however, to cover all costs if exploration activities are not successful or the production is disappointing. The fee for this guaranty is an increased interest to DONG VE. A gradual development is expected and two major obstacles are foreseen:

- At most localities the existing production plants has several years remaining production life before a renewal or major renovation will be needed. Owners of such plants will compare with existing variable costs only and often be reluctant to cut back their production to give space on the market for geothermal heat.
- The Danish heat and power production is highly regulated, and a new geothermal production will not always fit into existing plans. Further geothermal heat carries a fiscal problem, as it does not have the same potential for taxation as the fossil fuels. This may make the authorities want to limit the geothermal production.

Despite of the above-mentioned obstacles geothermal heat has so many advantages in relation to environment, security of supply and stabilization of prices for heating that the geothermal production is expected to increase significantly in the future.

Key words: geothermal, direct-use, space heating, low enthalpy, Thisted, Copenhagen, absorption heat pumps, sandstone, injection, Denmark.



Geothermal Plant Screening

03/10-04 16:30 DONG VE, ama.

Pumps	Prod. bar		Inj. bar	
Aquifer	12,7	10,6	22,6	18,5
Skin	0,0	0,0	4,1	3,4
Tubing	2,3	1,6	3,2	2,2
Static	2,6	2,6	-4,4	-4,4
Wellhd.	11,2	11,2	-7,2	-7,2
Pump.dP	28,8	26,0	18,4	12,6

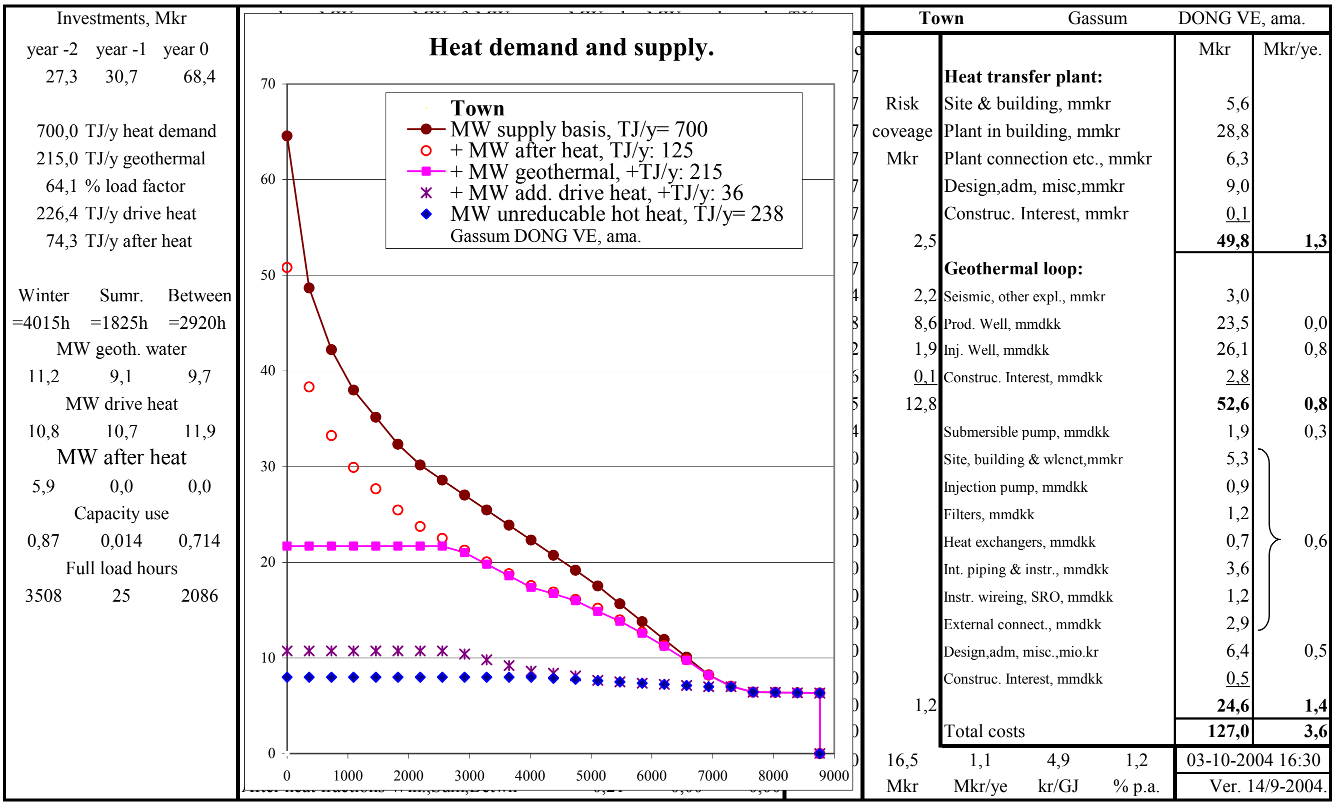
Investment:	Mkr
Exploration & wells	52,6
Others, geoth. loop	17,7
Heat transfer plant	40,7
Design,adm, misc.	15,3
Construc. Interest	3,5
Total	**129,8**

CHP & boiler drive COP: **8,7** **16,9**

	CHP drive heat		Boiler drive heat		70kr/GJ drive ht.	
Ver. 14/9-2004.	MW	TJ/ye	MW	TJ/ye		TJ/ye
Heat sold	11,3	229,3	10,6	215,0	21,8	441,4
Power 700buy 550loss	1,3	26,3	0,6	12,7	0,6	12,7
Hours yearly 5620	Mkr/ye.	kr/GJ	Mkr/ye.	kr/GJ	Mkr/ye.	kr/GJ
CAPEX 4,0 %, 25ye.	8,3	36,2	8,3	38,6	8,3	18,8
OPEX except energy	3,6	15,5	3,6	16,6	3,6	8,1
Power & driving heat	4,7	20,3	2,5	11,5	18,3	41,5
Production costs	16,5	**72**	14,3	**66,7**	30,2	**68**

Default Darcy ref. depth: 1,28 Default °C ref. depth: 50,7 Information level 2 Copy file 12

Figure 12.1: First page of example of output from screening program calculating heat production costs based on a minimum of input parameters creating a simplified duration curve.


Investments, Mkr
year -2 year -1 year 0
27,3 30,7 68,4

700,0 TJ/y heat demand
215,0 TJ/y geothermal
64,1 % load factor
226,4 TJ/y drive heat
74,3 TJ/y after heat

Winter	Sumr.	Between
=4015h	=1825h	=2920h
MW geoth. water		
11,2	9,1	9,7
MW drive heat		
10,8	10,7	11,9
MW after heat		
5,9	0,0	0,0
Capacity use		
0,87	0,014	0,714
Full load hours		
3508	25	2086

Town		Gassum	DONG VE, ama.
		Mkr	Mkr/ye.
	Heat transfer plant:		
Risk	Site & building, mmkr	5,6	
coveage	Plant in building, mmkr	28,8	
Mkr	Plant connection etc., mmkr	6,3	
	Design,adm, misc,mmkr	9,0	
	Construc. Interest, mmkr	0,1	
2,5		**49,8**	**1,3**
	Geothermal loop:		
2,2	Seismic, other expl., mmkr	3,0	
8,6	Prod. Well, mmdkk	23,5	0,0
1,9	Inj. Well, mmdkk	26,1	0,8
0,1	Construc. Interest, mmdkk	2,8	
12,8		**52,6**	**0,8**
	Submersible pump, mmdkk	1,9	0,3
	Site, building & wlcnct,mmkr	5,3	
	Injection pump, mmdkk	0,9	
	Filters, mmdkk	1,2	
	Heat exchangers, mmdkk	0,7	0,6
	Int. piping & instr., mmdkk	3,6	
	Instr. wireing, SRO, mmdkk	1,2	
	External connect., mmdkk	2,9	
	Design,adm, misc.,mio.kr	6,4	0,5
	Construc. Interest, mmdkk	0,5	
1,2		**24,6**	**1,4**
	Total costs	**127,0**	**3,6**

16,5	1,1	4,9	1,2	03-10-2004 16:30
Mkr	Mkr/ye	kr/GJ	% p.a.	Ver. 14/9-2004.

Figure 12.2: Second page of example of output from screening program calculating heat production costs based on a minimum of input parameters creating a simplified duration curve.

Locality	Type[1)]	Maximum Utilization			Capacity[3)]	Annual Utilization		
		Flow Rate	Temperature (°C)			Ave. Flow	Energy[4)]	Capacity
		(kg/s)	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5)]
Thisted	D	61	44	11	7,0	22,0	80	0,36
Copenhagen	D	73	73	17	14,2	62,1	380	0,85
TOTAL		134	117	28	21	84	460	

Note:

Both plants transfer heat through absorption heat pumps and the listed heat is the heat extracted from the gothermal water
Data for the Copenhagen Plant are expected data based on early test runs

Figure 13: Expected heat production as of December 2004

Locality	Ground or water temp. (°C)1)	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type2)	COP3)	Heating Equivalent Full Load Hr/Year4)	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)
	8							
Approx. 250 ground water based heat pump units were installed in the early eighties and around 43.000 other heat pumps are in operation today extracting heat primary from air and secondary from vertical tubes in the soil. (the percentage is not known, but maybe 10-20% from the vertical tubes)								
The extracted heat is approx. 3900 TJ annually, the average system COP is around 3.0								
Some industrial cooling systems using ground water has been installed, but the Danish climate does not call for geothermal cooling.								
TOTAL								

Note: Heat extracted from deep geothermal wells through absorption heat pumps is not included in the above

Figure 14: Ground source heat pumps

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1990-1994	1	0			100	0
1995-1999	1	4,5	1		10	90
2000-2004	1	33	1		90	10

Note:
Rough estimate of Danish paid projects inside and outside Denmark plus EU-paid projects within Denmark. Projects based on shallow wells are not included.

Figure 15: Geothermal investments