Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Country Update Report for Denmark

Allan Mahler and Jesper Magtengaard

DONG Energy, A. C. Meyers Vænge 9, DK-2450 Copenhagen SV, Denmark

allma@dongenergy.dk

Keywords: Thisted, Copenhagen, Sønderborg, geothermal, direct-use, district heating, low enthalpy, absorption heat pumps, sandstone, injection, power storage, Denmark

ABSTRACT

The first geothermal plant in Denmark based on deep wells was established in 1984 and later expanded to produce up to 7 MW heat from 200 m^3/h of 44 °C, 15 % saline geothermal water with production from and reinjection in a sandstone aquifer at 1,250 m depth. The second plant situated in Copenhagen started production in 2005 designed to produce up to 14 MW heat from 235 m^3/h of 73 °C, 19 % saline geothermal water from a sandstone aquifer at 2,560 m depth.

DONG Energy has taken out licenses and has erected and operates plants together with local partners. New contacts have been established with a number of towns to look into the options there. A seismic survey has been carried out in Sønderborg to prepare the drilling of a geothermal doublet late in 2009 planned to produce 15 MW heat from 250 m^3/h of around 68 °C, 21 % saline geothermal water from a sandstone aquifer at 2.1 km depth. Negotiations have been initiated to prepare the establishment of a geothermal plant in Hjørring producing up to 17 MW heat from 300 m^3/h of around 65 °C, 20 % saline geothermal water from a sandstone aquifer at 2 km depth and other towns are interested. The geothermal plant in Thisted may also be expanded further. Preliminary plans exist to erect a geothermal plant in Copenhagen with 11 wells of which some of the production wells can be used for long term heat storage. The heating plan for Copenhagen includes an option to install 400 MW geothermal heating capacity.

Danish aquifers are normally not suitable for power production as sufficiently permeable layers are too cold. They may, however, be used for power production based on stored heat from the sun, excess incineration plant heat etc. or heat pumps driven by excess wind turbine power.

The number of smaller heat pumps extracting heat from ground water and topsoil has been assessed to around 20,000 with an average COP of approx. 3 and a total heat production at 2 PJ/year.

1. INTRODUCTION

This paper focuses on geothermal heat from deep wells. Heat production based on ground water and heat accumulated in near surface layer is, however, assessed in "1.1 Plants based on ground water and Topsoil”.

Denmark has moderate temperature gradients, but widespread geothermal aquifers and district heating networks in most of the Danish towns supplying heat to 60 % of Danish houses. Aquifers have been identified around many of these towns with sufficient heat to cover 20 – 50 % of their heat demand for hundreds of years.

A recent study has assessed the reserves in a licence for Greater Copenhagen Area to 60,000 PJ or 1/3 of the heat demand for about 5000 years. This study is reported in the paper “Geothermal reserves and sustainability in the Greater Copenhagen Area”.

Present plants use absorption heat pumps, which can be driven for free by other district heat producers such as boilers based on biomass or incineration - or heat from combined heat and power plants (CHP plants) without low pressure steam turbines.

The Danish legal framework is in place and there is an increasing interest in geothermal energy among district heating companies and municipalities. Geothermal plants receive no funding, but high taxes on fuels and the focusing on CO_2 makes it attractive to substitute the burning of fossil fuels on CHP plants with wind turbine power and geothermal heat.

Geothermal plants can be used for long term heat storage with low losses. The heat to be stored may e.g. come from incineration plants producing more heat than needed in the summer time or from heat pumps driven by surplus power production form wind turbines etc. Stored hot heat may be produced without heat pumps by direct heat exchange or be used as driving heat for absorption heat pumps. Stored hot heat may also be used for power production making it possible to store wind turbine power using heat pumps or storing incineration plant heat and heat from biogas boilers instead of using it for power production in periods with excess wind power.

DONG Energy holds licenses at major cities alone or as partner in a license, e.g. in Thisted, Greater Copenhagen and Sønderborg and has provided assistance to designing, erection and operation of geothermal plants abroad. DONG Energy works closely together with GEUS (Geological Survey of Denmark and Greenland) concerning geological mapping and evaluation of reservoirs and Aarhus University has mapped the temperatures.

The business concept for Dong Energy is to establish, own and operate geothermal plants in partnership with local district heating companies, where the district heating company pays the operating costs and an indexed loan mortgage on DONG Energy’s investment, where the interest can include a warranty reducing the payment if the production capacity is reduced.

The company Dansk Geotermi specializing in the reuse of dry hydrocarbon wells plans to assist the district heating company in Viborg reopening such a well to supply geothermal heat.

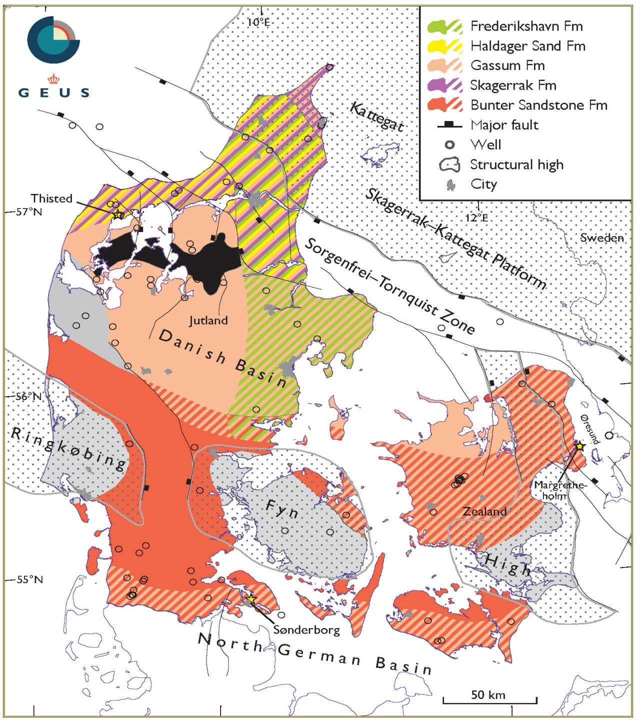

Figure 1: Map showing the existing plant locations and the principal structural elements.

1.1 Plants based on groundwater and topsoil.

Approximately 250 ground water based heat pump units were installed in the early eighties and around 20,000 heat pumps are in operation today extracting heat from the ground, primary from vertical tubes in the topsoil.

The heat supply from the electric driven heat pumps extracting heat from ground water and topsoil has been assessed to 2 PJ. Nearly all of the heat is used for domestic heating. The average COP is estimated to 3.

Ground water is also used for cooling, e.g. industrial and some projects will combine heating and cooling using ground water or ground heat exchangers. The cooling capacity in 18 larger present and planned aquifer thermal energy storage projects was in 2007 assessed to a total of just below 30 MW.

2. GEOLOGY, RESSOURCES AND RESERVES

The geothermal production is related to permeable sandstone layers. Diagenetic cementation generally increases with depth preventing the use of layers deeper than 2.5 - 3 km. This limits the maximum temperatures to 80 - 90 ^{o}C.

2.1 Geology

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

Through geological time 5 sandstone reservoirs of major potential have been deposited sourced mainly from the Skagerrak-Kattegat Platform and Ringkøbing-Fyn High.

Most reservoirs are situated in the Danish Basin. The largest reservoirs are the Gassum Formation and the Bunter Formation. The Frederikshavn Formation, the Haldager Formation and the Skagerrak Formation also have god potentials at some locations.

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.

The depths of the reservoirs vary considerably from area to area. General investigations must be supplemented by seismic surveys and other local assessments to estimate local production potentials.

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 the Bunter Formation has 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 tends 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 8 °C + 28 °C per km depth
- The salinity is at around 10 % per km depth
- The permeability is at around 1 Darcy at 1.5 km's depth and it is halved around each 300 m or 10 °C.

The geothermal resources have been assessed in "Atlas of geothermal resources in Europe" issued by the European Commission in 2002.

2.3 Geothermal reserves

The reserves in Denmark have not been assessed, but the partners in the Greater Copenhagen geothermal license in Denmark have completed a study of the geothermal reserves in that area. The results are presented in paper 0503 from which the abstract and an example of a reserve estimate for the license area is enclosed below.

Three main sandstone reservoirs have been identified and described in 462 blocks each of an area of 4 km^2. The decrease of production temperature with time at a geothermal plant with moderate, but commercial production rates has been modeled over 500 years. The results show, that the production temperature decreases relatively slowly due to a significant flow of heat from the layers above and below the reservoirs partly reheating the injected water. The production can thus be continued for many decades when commercial at a lower production temperature than the initial reservoir temperature.

The modeling was also used to establish a generalized correlation between production temperature as fraction of initial temperature and produced fraction of heat in gross reservoir. Another computer program estimating geothermal heat production costs was used to establish a generalized relation between transmissivity and a lower temperature limit for commercial production.

These two generalized relations were then combined with an assessment of the transmissivity and the initial temperature and heat in place in each of the 462 blocks to calculate the commercially producible heat from each block.

The thus producible heat at a chosen commercial cut off heat price in the Greater Copenhagen area reaches 60,000 PJ. Compared to the district heat consumption for the area of 40 PJ/year, the underground is seen to have a capacity to supply whatever heat is needed for thousands of years.

A simulation of the reheating of reservoirs to estimate the temperature distribution with depth after 5000 years shows that the reheating of the reservoirs by then has given a substantial contribution to the reserves.

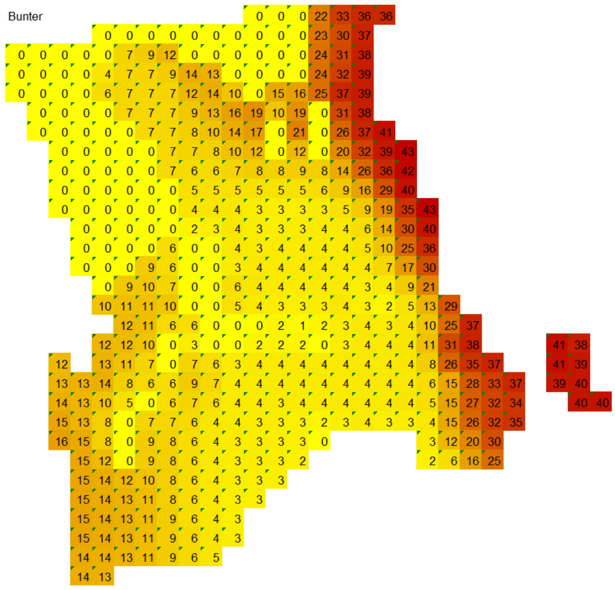

Figure 2: Example of reserve estimate in GJ/m^2.

3. GEOTHERMAL CONCESSIONS

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.

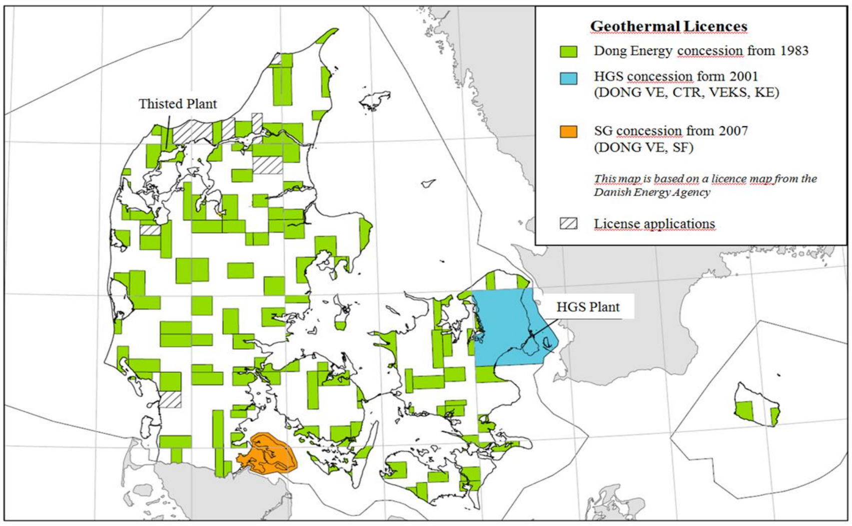

Figure 3: Geothermal license map

The sale of heat to district heating systems is regulated to protect the customers. Generally the price is only allowed to include certain well defined elements as pay back of normal plant loans, purchase of fuel and power, maintenance and administration. Geothermal plants are, however, allowed to include a profit to finance risks to be approved by a national board, Energitilsynet**.**

4. PRESENT AND PLANNED PRODUCTION

Two plants are erected and in operation in Denmark. The Thisted Plant has been in operation since 1984, and the HGS plant in Copenhagen at Margretheholm started production in 2005. The locations are shown on figure 1.

The present annual geothermal district heating production is at about 380 TJ. Around USD 60 million (€ 43 million), hereof approximately 90 % private, has been invested in the use of geothermal heat for district heating. Please refer to Figure 11 and 12 enclosed at the end of this paper.

4.1 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. It was enlarged using absorption heat pumps to extract 4 MW from 150 m^3/h geothermal water in 1988 and 7 MW from 200 m^3/h geothermal water in 2001.

This plant was described in great detail in earlier WGC papers. Annual corrosion rates in carbon steel exposed to the geothermal water are at 0.06 mm and good productivity and injectivity has been maintained.

43 ^oC warm, 15 w% saline water is produced from a high permeable Gassum sandstone aquifer at 1,250 m depth filtered to about 2 micron in bag filters before the heat extraction and to about 1 micron in cartridge filters before reinjection. The wells are vertical and located 1.5 km apart with injection pump and cartridge filters facilities at the injection site.

The plant has carbon steel piping with 3 mm corrosion allowance and AISI 316 moving parts in valves. It 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 system is flushed to the sea at restarts.

The heat is transferred to the district heating network through absorption heat pumps driven by a straw based boiler. They are driven for free as the boiler uses the same amount of straw when producing heat through the absorption heat pumps to the district heating network as it does, when producing directly to the network. The local incineration CHP plant can also drive the heat pumps. The power to heat ratio (COP) for the geothermal plant in Thisted is at 15 - 20 depending on the load.

DONG Energy owns and has the responsibility for the operation principles for the geothermal loop comprising wells and surface facilities containing geothermal water. The district heating company, Thisted Varmeforsyning, takes care of the daily operation and owns and operates the heat pump plant and the district heating network.

The total investment costs are € 11.1 million including costs for the Pilot Plant and the deep explorative production well.

€ million invested in the period 1982 – 2001 (1 € = 7.5 DKK).

Explorative 3.3 km production well	3.8
1.3 km reinjection well	1.4
30 m^3/h surface plant	1.8
Geothermal loop expansion to150 m^3/h	0.4
Surface plant expansion to 4 MW	2.2
Plant expansion to 7 MW	1.5
Total	11.1

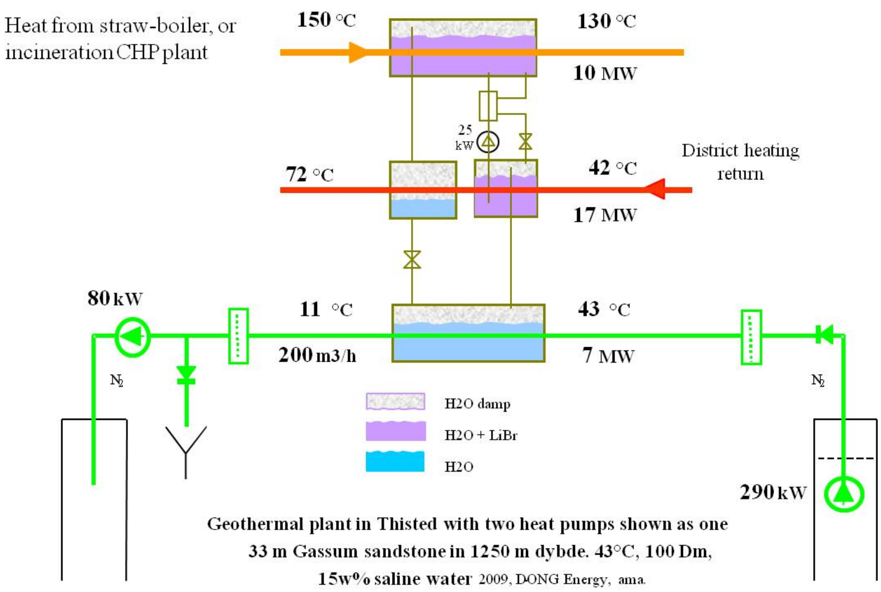

Figure 4: Geothermal plant in Thisted

A basis for a future increased geothermal production in the Thisted area is emerging as some small local district heating companies are looking into the possibility to connect to the district heating network in Thisted. Such plans could create a basis for an increase in the demand for geothermal production and thus investments in new wells in the license area.

4.2 Geothermal plant in Copenhagen

The Establishment of geothermal plant in Copenhagen was reported in the WGC 2005 paper and is summed up shortly here together with construction costs and operating experience.

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

A site next to the Amager CHP plant was chosen with access to driving heat for absorption heat pumps and easy access to lead well test water to the sea. The first well was drilled vertically to the basement situated in 2.7 km depth during the summer 2002.

Tests and evaluations showed that the Bunter Formation at 2.6 km depth could be produced at acceptable rates 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 have a good communication to the first well.

The construction of the surface plant to extract 14 MW heat from 235 m^3/h of the 73 °C, 19 % saline geothermal water started in 2003 with DONG Energy as operator.

The heat pump plant with 3 absorption heat pumps in series is located close to the Amager CHP plant approximately 800 m from the geothermal loop plant located next to the wells at the sea front.

The geothermal water in the Copenhagen plant has a higher CO_2 content and salinity than in Thisted. The geothermal loop is designed with carbon steel piping with 5 mm corrosion allowance, AISI 316 filter houses with corrosion protection rods and tall titanium plate heat exchangers in the geothermal loop.

The plant was designed to produce up to 14 MW from 235 m3/h of 73°C, 19 w% saline water. Three absorption heat pumps in series cool district heating return water at about 50 °C to 15 °C to be heated to 71 °C in the heat exchanger at the geothermal loop plant. The district heating water from the heat exchanger is mixed with district heating water preheated to the same temperature in the absorbers and the condensers supply the remaining heat to reach a supply temperature at up to 85 °C.

When starting up the plant it was found that the bubble point was higher than calculated from water/gas samples. The production wellhead pressure was therefore increased to 15 BARa requiring the removal of two submersible pump steps to gain speed and thereby more horsepower in the pump. The high bubble point (at around 20 bar) has also required a system for removing gasses at the plate heat exchanger top and injection pump inlet.

Measured corrosion rates in carbon steel are at up to 0.2 mm annually and thus acceptable at the 5 mm corrosion allowance design.

Sand production from casing perforations and a not fully successful clean up of the wells has lead to the installation of a self cleaning pre-filtering unit with perforated pipes back-flushed and scraped at the same time when cleaned.

Additional cleaning of the injection well was also required and it has been pumped clean using the pump from the production well and also cleaned by soft acidizing adding inhibited acid to the injection water flow.

The geothermal water is pumped to the surface by a 700 kW submersible pump located at 650 m depth, pre-filtered to 30 micron in the self cleaning filter unit, filtered in bag filters to 2 micron, cooled from 74 °C to 17 °C in long titanium plate heat exchangers, filtered to 1 micron in cartridge filters and reinjected at up to 70 bar using a 700 kW injection pump.

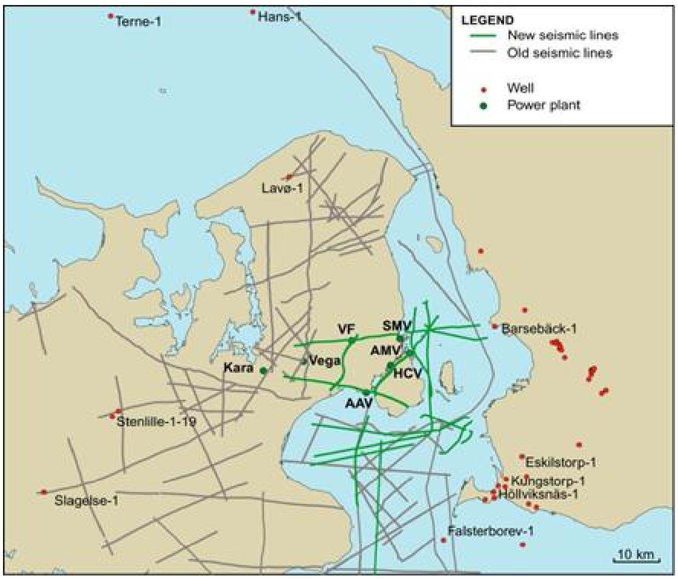

Figure 5: Seismic lines

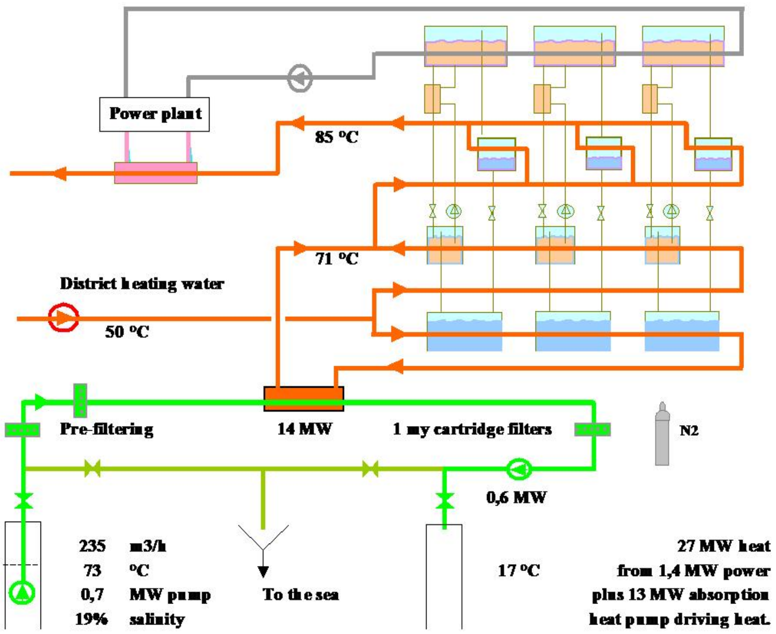

Figure 6: Geothermal plant in Copenhagen extracting heat using heat exchangers and absorption heat pumps.

When starting the plant water is for some hours pumped to the cooling channel at the CHP plant to avoid plugging up the filters with sand and corrosion products from the well and to be sure not to inject air contaminated water.

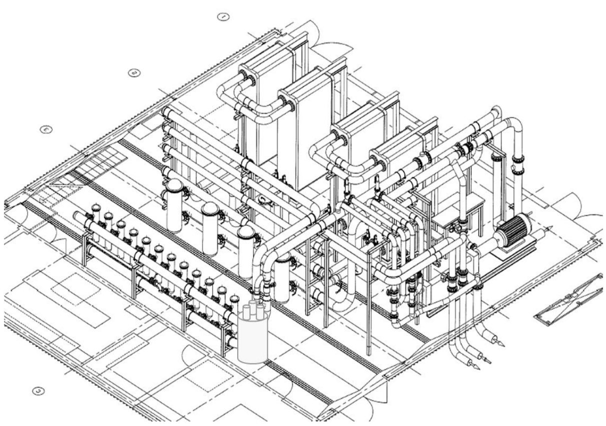

Figure 7: Geothermal loop in building

The plant was initially designed to receive 13 MW driving heat steam from a turbine outlet on the CHP plant and later changed to be supplied from a steam net receiving steam from primarily biomass and incineration CHP plants.

The investment costs are shown below.

€ million invested in the period 1999 – 2005 (1 € = 7.5 DKK).

Exploration including 314 km seismic	2.3
2.7 km vertical well & tests	6.3
2.7 km TVD production well	6.8
Surface plant	12.9
Total	28.3

With the initial problems overcome the geothermal plant is regarded as a positive demonstration of the possibilities.

The HGS partners have late 2007 looked into the possibilities of expanding the geothermal plant to 70 MW from the underground adding new surface facilities and 9 new wells. This expansion leads to a Star-plant having all wellheads and surface facilities in one location with the wells deviating in all directions to an individual distance in the reservoir exceeding 1 km.

The Star-plant concept has been adopted in scenarios in the climate plan as well as in the heating plan for Copenhagen. Both these plans will be processed in the political assemblies late 2009. If the plans are realized up to 3 star-plants with 200 MW in capacity could be erected before 2050 with a long term perspective to reach 400 MW.

4.3 Geothermal plant in Sønderborg

Negotiations with a view to establish a geothermal plant in Sønderborg in a partnership between DONG Energy and the district heating company, Sønderborg Fjernvarme were initiated in 2005.

A cooperation agreement was signed in 2007 and a license for the area was granted in 2007 after some difficulties to reach an agreement with existing heat producers. A seismic survey was made the same year with a positive result and the production and injection wells are planned to be drilled and tested late 2009.

The primary well target is the Bunter sandstone expected to be found at 2.1 km with the Gassum sandstone at 1 km depth as a fall-back option. The production is planned to start end 2011 producing up to 15 MW heat from 250 m^3/h of about 21 w% saline geothermal water at 65 - 70 °C.

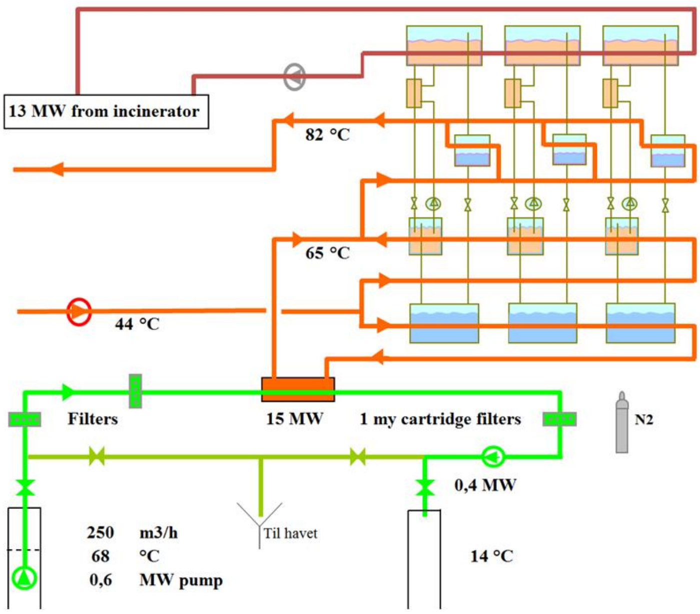

Figure 8: Planned geothermal plant in Sønderborg.

The well site established in the summer 2009 is located 3 km from the heat pump plant with absorption heat pumps which will be placed at the incineration plant and gas turbine CHP plant in Sønderborg. The absorption heat pumps are planned driven by steam from the incineration plant and / or or new biomass boilers.

The heat pumps in Sønderborg are shall cool 44 °C district heating return water to be reheated to about 65 °C in titanium *plate heat exchangers placed at the geothermal loop plant* at the well site. The thereby extracted 15 MW heat from thermal water geothermal is planned to be added to 13 MW driving heat for the absorption heat pumps delivering 28 MW heat at 82 °C supply temperature..

5. HEAT AND POWER STORAGE

Geothermal plants can be used for long term heat storage preferably using a dedicated well for the storage designed for the temperature level with space for a pump and the injection flow. Large plants with many wells may use production wells otherwise not used in the summer to store heat.

Compared to storage in ground water heat losses are much smaller on geothermal plants with deep wells where the geothermal water stays in place and loose less heat to the warmer surrounding earth layers.

The possibility to produce more water than injected in storage wells on geothermal plants reduce heat losses and simulations indicate, that 90 % or more of the stored heat can be recovered after some storage cycles.

Heat to be stored may e.g. come from incineration plants producing more heat than needed in the summer time or be produced by heat pumps when wind turbines etc. produce more power than needed. The heat may be stored at geothermal plants with absorption heat pumps at 3 different temperature levels:

- Above the district heat supply temperature of about 80 °C making it possible to produce stored heat without heat pumps. The heat to be stored can e.g. come from a geothermal plant with heat pumps in periods with excess heating capacity.

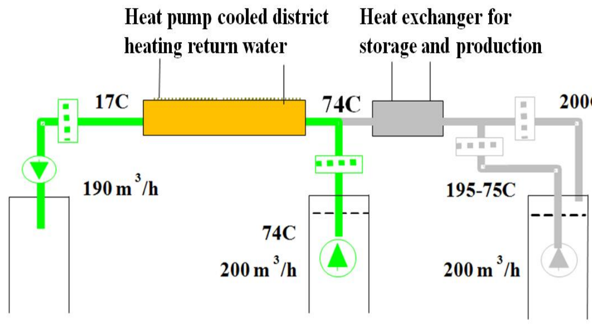

Figure 9: Heat storage concept example

- Above absorption heat pump driving temperature at around 160°C making it possible to use stored heat as driving heat and after heating. The heat to be stored can come from wind turbine driven heat pumps or normal driving heat suppliers, e.g. incineration plants in periods with excess heating capacity.

- At high temperatures suitable for power production. The heat to be stored can e.g. come from wind turbine driven heat pumps, biogas boilers or incineration plants.

Danish aquifers are in general not suitable for power production because of the low permeabilities in aquifers located deep enough to be warm enough to produce power.

Aquifers with hot stored heat can, however, be highly permeable and suitable for power production. Geothermal plants with heat storage can then be used for large scale storage of power from wind turbines, wave power and solar power etc. if / where financially feasible. Heat from the sun and other heat sources may also be stored and used later for power production.

Power may be stored increasing the temperature in aquifers to a level suitable for power production using heat pumps driven by excess wind turbine power. The process creates losses but it can benefit from a high initial temperature of the aquifer compared to the possible lower temperature of the heat receiver, e.g. Sea water when producing the power.

Hot heat from incineration CHP plants can be stored when not needing the power and be used for later power production. Geothermal heat can increase CHP power production when covering heat demand and facilitating condensing on cold sea water.

Geothermal plants with heat and- or power storage can be developed to supplement wind turbines etc. to save fuel on conventional heat and power producing plants.

Heat storage on geothermal plants is a concept that several district heating companies find interesting. A study together with Danish universities is planned carried out in 2010-2012 to evaluate the Danish reservoirs suitability for storing heat at high temperatures.

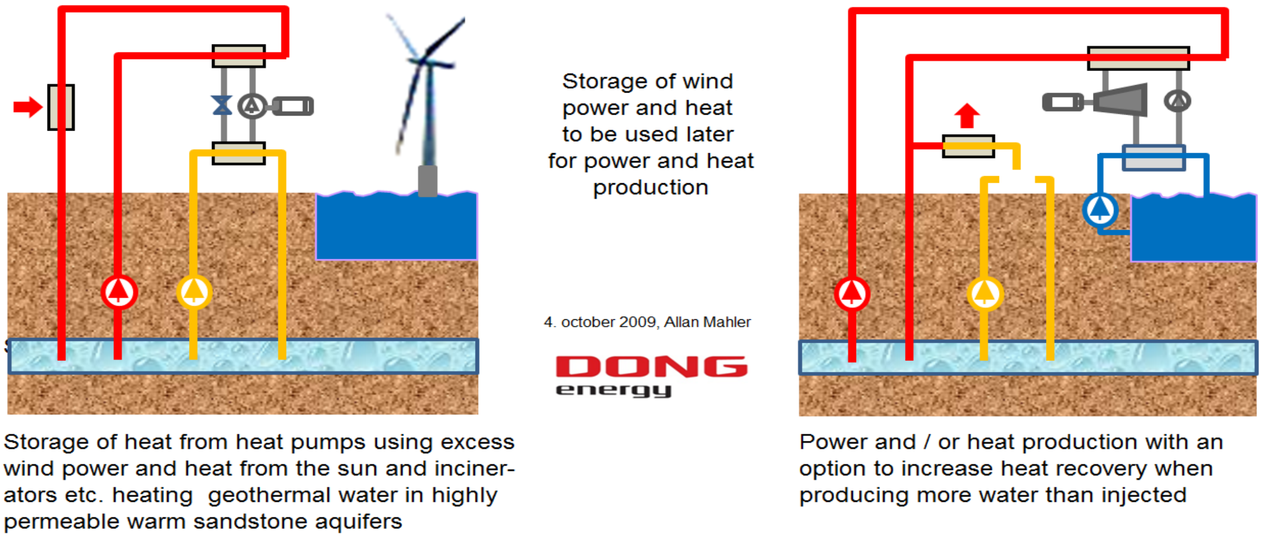

Figure 10: Storage of power using heat pumps to store hot heat in high permeable layers

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT

Locality	Type	Maximum Utilization			Capacity	Annual Utilization		
		Flow Rate (kg/s)	Temperature (°C) Inlet	Outlet	(MWt)	Ave. Flow (kg/s)	Energy (TJ/yr)	Capacity Factor[5)]
Thisted	D	61	44	11	7,0	22	80	0,36
Copenhagen	D	73	73	17	14	50	300	0,68
TOTAL		134			21		380	

The heat is transferred using heat exchangers and absorption heat pumps. The above heat is the heat for district heating extracted from the gorthermal water and not including heat pump drive heat. The geothermal water is highly saline reducing the heat capacity

Figure 11: Heat production through heat exchangers and absorption heat pumps as of December 2009

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES

Use	Installed Capacity (MWt)	Annual Energy Use (TJ/yr = 10^{12} J/yr)	Capacity Factor
Geothermal Heat Pumps			
For individual heating	160	1700	0,34
For district heating	44	800	0,57
TOTAL	200	2500	0,39

All geothermal heat is produced through heat pumps. Output from heat pumps is shown.
The heat pumps for district heating are absorption heat pumps and the rest are electrical.
Individual heating is a rough estimate, Work has been initiated to improve data.
Some groundwater is used for cooling, primary industrial. The amount is unknown.

Figure 12: Heat production as of December 2009

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2009) US$

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$	%	%
1995-1999	1	5,5	1		10	90
2000-2004	1	36	1		90	10
2006-2009	1	20	1		100	

Estimated costs for deep well based projects. Includes Danish paid projects abroad in period 1995-2004. DONG Energy, a stock holding company with state owned stocs and consumer owned district heating companies and utilities are anclosed as Private investors. Former investments have partly been adjusted for inflation, but not for changes in US$ exchange rates.

Figure 13: Geothermal investments