ECES Annex 12

"High Temperature Underground Thermal Energy Storage"

9th report to the Executive Committee
25.-26.4.2002

Annex 12 of the ECES Implementing Agreement of IEA is a task-sharing annex. There are four countries participating in the annex, comprising the locations of most of the operational HT-UTES plants and the institutions where work towards HT-UTES is done:

- Belgium
- Canada
- Germany
- Sweden

A fifth country, the Netherlands, where the only other operational HT-UTES is located, is participating through some industry involvement and assistance to the work of the annex. Norway attended the experts meeting in spring 2001 as an observer.
Funding for the work is fully available in Belgium, Germany and Sweden, and is currently not clear in Canada.

Two experts meetings have been conducted since the last ExCom meeting:
XM 8, Neubrandenburg, D, November 2001
XM 9, Malmö, S, April 2002
The minutes of this meeting are given as Appendix A and B, respectively.

Work on monitoring and on the site test methods for aquifer chemistry and ground thermal parameters is continuing. Currently monitored are:

- Neckarsulm, BTES (D)
- Rostock, ATES (D)
- Berlin, ATES (D)
- Hooge Burch, ATES (NL)
- Anneberg, BTES (S)

New HT-UTES projects are under construction or in planning, and will be monitored:

- Attenkirchen, BTES (D) start of operation spring 2002
- Neubrandenburg, ATES (D) start of operation fall 2002 (?)
- Mol, BTES (B) start of operation summer 2002

For Attenkrchen and Mol, only the experiences from the design and construction phase will be available for the phase 2 final report.

The test equipment for aquifer chemistry and groundwater behaviour could be made operational in Stuttgart, Germany, and further completed in Lüneburg. Outside these sites the equipment has been used on 3 locations now:

- Nijmegen (NL)
- Pellworm Island (D)
- Frankfurt/Main (D)

In most cases, only calcite as scaling was found. A kind of scaling sensitivity curves with increasing temperature has been developed.
A first summary report for this work has been completed by Stuttgart university.

For borehole heat exchangers, many more thermal response tests have been done in the participating countries, mainly in Germany and Sweden. Guidelines are under development together with Annex 13. Participation to a workshop on that topic at Lausanne Technical University, conducted by the Swiss colleagues, in October 2001 provided further information.

Economic data have been collected and evaluated for the plants in Attenkirchen, Neckarsulm, Rostock and Mol.

For completing phase 2, the following plan and schedule has been established:

Subtask B: Monitoring:

Project	Data	Responsible
Reichstag	data up to date, only storage loading	GTN/JLU Giessen
Rostock	data of almost one cycle	Thomas Schmidt
Neckarsulm	data of 1st extension	Thomas Schmidt
Hooge Burch	???	IF ???

Subtask C: Aquifer Test Equipment - Report on Construction and first tests

Subtask D: TRT - Summary Report as related to high temperature

Subtask F: Economy - Data for 4 plants evaluated

Additional: Update of phase 1 fact sheets for new and enlarged projects

Task completion schedule (by end of 2002).

- Provide missing information as discussed at the Malmö meeting and complete the monitoring to the dates set
- Compilation of phase 2 draft report over the summer months 2002
- Review phase 2 draft report at XM 10 in autumn 2002
- Print and distribute phase 2 report before the end of 2002

Future plan:

Continue monitoring the existing systems and the new plants to become operational in 2002/2003, either as a phase 3 of Annex 12 or as a new Annex, to be starting full force in the second half of 2003

New Annex idea, discussed at XM 8:

Proposal should be discussed regarding an annex on optimization of BHE and BHE systems, incl. thermal response testing, thermally enhanced grouts, etc. (might be a joint annex under ECES together with Heat Pumps and Geothermal ?)Publication information:

An international summer school on geothermal energy was held in Bad Urach, Germany, in September 2001, including a 3-day course on geothermal heat pumps. The course material will be available on-line on the homepage of the institute; the table of contents already can be seen under:

http://www.uni-giessen.de/~gg1068/html/literatur_tagungsberichte.html

or under

http://www.geothermie.de

The Proceedings of the Thermal Response Test Workshop in Lausanne, Switzerland, have been printed (published by GtV, Gartenstrasse 36, D-49744 Geeste, Germany, Fax +49 5907 7379), and contain, as an appendix, the draft Annex 13 TRT guidelines

Report given by: Dr. Burkhard Sanner
Operating Agent Annex 12

Appendix A

Minutes of the 8th Expert´s Meeting in IEA ECES Annex 12 High Temperature UTES

8.-9.11.2001, Neubrandenburg, Germany

Participants:
Burkhard Sanner, Justus-Liebig-University, Giessen (D)
Bert Gysen, Vito, Mol (B)
Göran Hellström, Lund University, Lund (S)
Manfred Reuß, ZAE Bayern, München (D)
Wolfgang Ruck, Univ. Lüneburg, Lüneburg (D)
Thomas Schmidt, ITW, Univ. Stuttgart, Stuttgart (D)
Guido Knoche, ISWA, Univ. Stuttgart, Stuttgart (D)
Frank Kabus, GTN GmbH, Neubrandenburg (D)

Begin 8.11.2001, 09:00
Offices ot GTN GmbH, Neubrandenburg

Country status

Country	Status	Participant
Belgium	member	VITO
Canada	member	Environment Canada
Germany	member	FZ Juelich / Giessen University
Netherlands	assitant	IF Technology
Sweden	member	FORSAS / TU Lund

Subtask B - Monitoring

Belgium

Bert Gysen

TESSAS Mol:
Project is now a little bit behind schedule due to problems with the tendering process for the borehole heat exchangers.
Hexagonal pattern with 2 m distance, 30 m deep, 12 additional boreholes for monitoring with a total of 66 sensors Pt100, some boreholes to a depth beneath the store.
Plan is to load with heat from district heating network (fossil fuel power plant close by).
Calculations show that in the steady operation pattern found in TESSAS, the difference in efficiency between single- and double-U-tubes is only marginal.

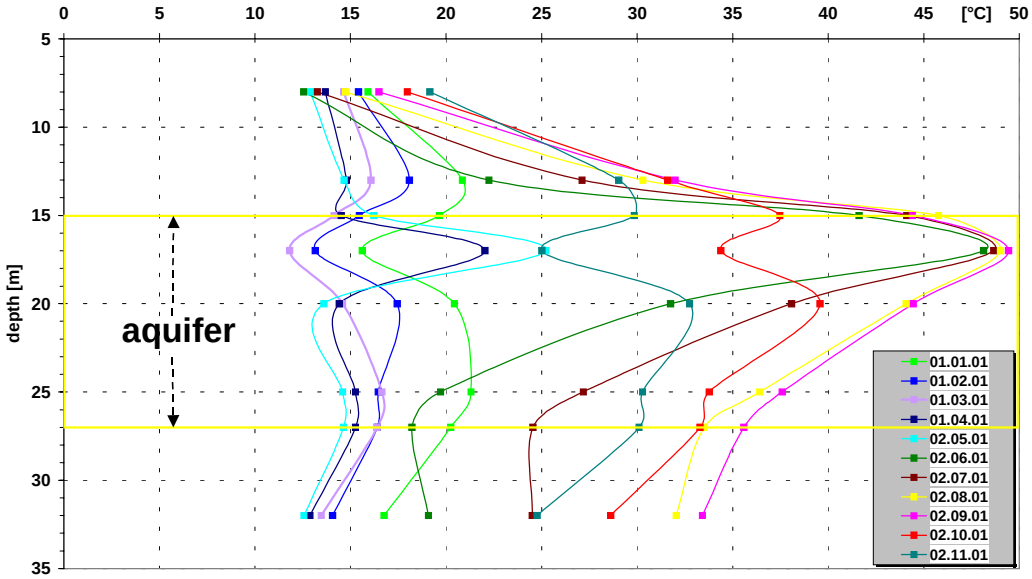
Germany

Thomas Schmidt

Rostock
ATES, temperatures in store up to 48 °C in the upper part in Sept. 2001
Problems with cold well (leakage), flow rate had to be reduced to 12 m^3/h (instead of 15 m^3/h).
Plans to rehabilitate the cold well (infos to and from Annex 13?)

ATES Rostock		2000 (20.4.-31.12.00)	2001 (1.1.-4.11.01)
heat charged	[MWh]	112	211
heat discharged	[MWh]	1	15
water charged	[m³]	2576	5475
water discharged	[m³]	873	3826

Figure: ATES Rostock – temperatures 5 m NW from the hot well in 2001



Neckarsulm
2nd extension finished, bringing store to a cumulative total of 528 BHE (pilot store 36 BHE, 1st extension 168 BHE)!
Temperatures 50-55 °C in Sept. 2000, only around 45-50 °C in Sept. 2001 (monitoring was resumed after reconstruction of manifold housings, so probably calibration required; see figures below).

Figure: Layout of store and location of temperature sensors in the ground, BTES Neckarsulm

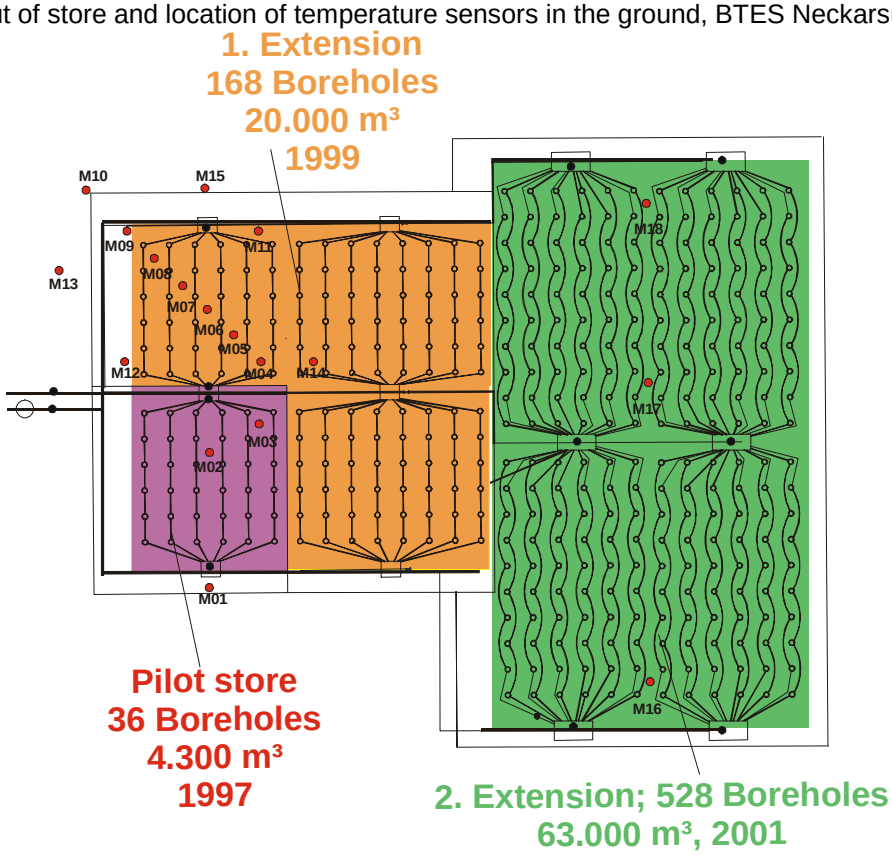
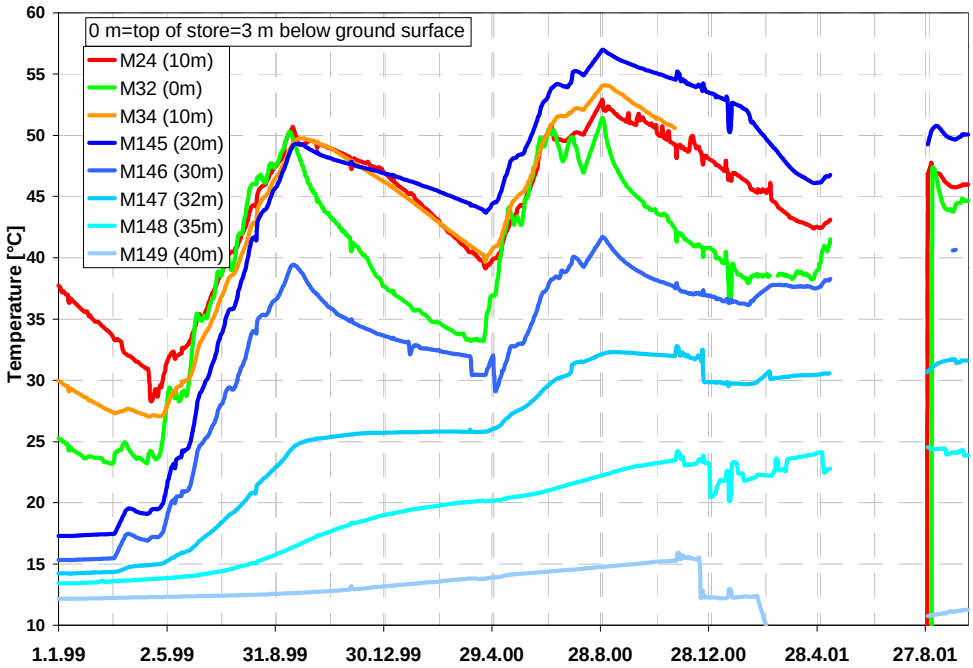


Figure: BTES Neckarsulm, temperatures in the ground (center)



Manfred Reuss

Attenkirchen
Pit with concrete walls ready, all drilling completed. BHE distance from pit wall had to be increased to 1.5 m (due to construction of pit wall foundation). Monitoring boreholes in a line over the whole store area and outside.
Two different types of grouting material used:

- AZ-BUT „Thermocem“ (graphite for thermal enhancement)

- standard bentonite/cement grout with quartz sand for thermal enhancement

Comparison in operation and thermal response testing planned.

Frank Kabus

Reichstag Berlin
Cogeneration plant in Reichstag building since 2000, delivering only ca. 200 kW of waste heat (rest is used directly); this limits storage loading temperature to ca. 30-40 °C. Cogeneration plant in Paul-Löbe-Haus will start operation in Dec. 2001 (heat storage will start after heating season).
Cold Storage: Cooling towers on Jakob-Kaiser-Haus are operational now, those on Paul-Löbe-Haus will follow ca. March 2002.

Neubrandenburg (new project)
Geothermal system, now out of operation, using 2 aquifers.
For storage, use of the lower aquifer at depth 1110-1270 m (Hettangian) is planned (2 wells)
Cogeneration plant produces 40 MW el. power and 40 MW heat, in summertime only ca. 20 MW of heat are required in the DH net, thus ca. 20 MW are wasted. The ATES should store ca. 5 MW of the extra heat. Flow rate up to 100 m^3/h, storage temperature up to 80 °C.

Sweden

Göran Hellström

Anneberg:
Solar BTES, Fully operational in March 2002, drilling completed.
Boreholes, BHE and solar collectors did cost as expected, but control, engineering etc. more expensive (control did cost more than BHE-field!).
Originally only basic monitoring planned, now programme enhanced.

Malmö (new project plan)
Geothermal exploration hole planned to a depth of 1800 m, also to investigate an aquifer for HT-ATES in 500 m depth.
HT-UTES for 25 MW thermal output, 90-95 °C loading temperature and retreiving temperature down to 55 °C. Heat source is from cogeneration. Plans for 4 alternatives:

- BTES with double-U-tube BHE: 1200 BHE 200 m
- BTES with open hole BHE: 600 BHE 200 m
- ATES in 500 m depth
- ATES in shallow depth

Calculated pay back time from 2 years (ATES) to 8 years (double-U-BTES)

Info on Ground Source Heat Pumps:
2000: 14000 GSHP
2001: 24000 GSHP (expected)
70 % of GSHP vertical, average BHE depth 128 m

Monitoring schedules

Type	Project	1st full operational cycle ends
ATES	Hooge Burch (NL)	2000?
	Reichstag (D)	summer 2003
	Rostock (D)	summer 2002
	Neubrandenburg (D)	fall 2003
BTES	Anneberg (S)	spring 2003
	Neckarsulm (D)	full system summer 2003
	Attenkirchen (D)	spring 2003
	Mol (B)	spring 2003

Annex 12 phase 2 ends June 2002:
At that date only preliminary cycles from Neckarulm (1st phase), Rostock and Hooge Burch will be completed, all other projects still under construction or without a full cycle under final operating conditions.

Annex 12 phase 3 on monitoring may start with a workshop summer/autumn 2003 (in connection with Futurestock?), to look at first completed cycles of all projects in table above. From autumn 2002 until summer 2003 either „dormant" annex, or close annex 12 and start with a new annex on monitoring in 2003.

Minimum data for monitoring

Minimum monitoring requirements

a) charging / discharging:

- ⇒ amount of heat charged / discharged
- ⇒ temperatures at charging / discharging
- ⇒ amount of water produced at charging / discharging (ATES only)

Determination of heat:
- supply and return temperatures of the store (/of parts of the store; well-groups, ...)
- flow through the store (/parts of the store) at charging / discharging

minimum resolution for calculation of heat: 10 minutes
alternatively two heat meters for charging / discharging with integration of flow

b) ground conditions:

- ⇒ temperatures in the ground
  - separate borehole / borehole from test drilling
  - resolution: one week / one month
- ⇒ groundwater-level
  - borehole from test drilling ⇒ monitoring well
  - resolution: ??
- ⇒ chemistry of groundwater
  - groundwater circuit
  - monitoring well ?
  - resolution: ??

Charging and discharging temperatures should be stored as daily mean values of T_{in} and T_{out} (weighted by flow) following the formula:

$$T_M = \frac{\sum^{i} T_i \cdot \dot{m}_i}{\sum \dot{m}_i}$$

Time resolution 10 min (if fast changes are found) or up to 1 hour in systems with slow changes.

Subtask C - ATES groundwater suitability and water treatment

Guido Knoche

3 Test sites: Stuttgart, Nijmegen, Pellworm
In Stuttgart, comparison between k-value method and Ca-load (k-value here is an indicator for heat exchanger efficiency)
see attached pdf-file with a paper from Sept. 2001

Wolfgang Ruck

Monitoring of the changes in k-value (heat exchanger efficiency):

- Stuttgart: virtually no change at 70 °C
  substantial and steady decrease at 80 °C and 90 °C.
- Pellworm: virtually no changes at 80 °C.

Problem: Scaling found also in the heat recovery heat exchanger, where the groundwater is cooled again. This may be due to flow of oversaturated water from the first heat exchanger and precipitation in the second. Further investigation required.

Subtask D - BTES ground parameter investigation and BHE optimization

Burkhard Sanner gives a short report from the Lausanne Response Test workshop. The proceedings will be available in printed form by the end of the year through GtV (see http://www.geothermie.de)

Göran Hellström reports work done together with Jeff Spitler:

- Comparison of different evaluation methods showed different results in the first hours, but converging after about one day.
- Influence of groundwater flow may show after some time (separation of curve from pure conduction curve), e.g. 18 hours in one case. What is the implication, if the separation point is at the end of the measuring time?

Measuring in a tunnel with 14 °C constant air temperature, 29 °C inside the trailer will lead to constant thermal losses (transmission losses) from the equipment. It was determined to be on the order of 200 W. Also, the thermal parameters measured with Thermal Response Test were higher than those on samples etc., probably due to some groundwater convection in the fractured rock.

Göran Hellström developed a 1-D-model for evaluation that runs ca. 30 s, compared to 2 hours of Jeff Spitler´s 2-D-cylindrical model

Manfred Reuss mentions power fluctuations and their implications.

Subtask F - System concepts and economy

Formula for storage cost agreed:

$$\text{storage cost} = \frac{\text{writing off} + \text{operation cost}}{\text{produced energy}}$$

Writing off periods:
Numbers given in table from *Bert Gysen* agreed. They reflect Belgian tradtition, but are similar to others, and for comparison reasons the individual plants should be evaluated to the same standards.
For writing off, the borehole drilling cost are considered as part of BHE cost.

Plants to be evaluated:

- Berlin — no chance to get the required data
- Rostock (incl. HP and buffer storage) — Thomas Schmidt
- Neckarsulm (incl buffer storage) — Thomas Schmidt
- Attenkirchen (inkl. HP) — Manfred Reuss
- Neubrandenburg — conversion, not representative
- Anneberg (incl. buffer storage) — Göran Hellström
- Mol (TESSAS) — Bert Gysen
- Hooge Burch ??? — IF ???

Task Completion Plan

Subtask B:

Monitored data should include everything that may be available by end of March 2002, see table.

Project	Data	Responsible
Reichstag	data up to that date, only storage loading	GTN/JLU Giessen
Rostock	data of almost one cycle	Thomas Schmidt
Neckarsulm	data of 1st extension	Thomas Schmidt
Hooge Burch	???	IF ???

Data:
- daily mean values of T_{in} and T_{out} (weighted by flow, see above)
- daily mean values of flow
- heat charged / discharged (monthly / yearly)
- temperatures in the ground (if available)
- ATES: amount of water produced at charging / discharging (monthly / yearly)

Data should include experiences from design, construction and operation

Update the Annex 12 phase 1 fact sheets, and add Rostock, Neckarsulm 2nd extension, TESSAS, Anneberg, Neubrandenburg (send info to *Burkhard Sanner*).

Subtask C:

Description of design, construction and operation experiences of the Mobile Test Equipment. Evaluation of test results incl. a minimum of two further tests (draft until XM 9)

Chemical development in the ATES plants (end of March 2002):
- Rostock (Wolfgang Ruck)
- Reichstag (Wolfgang Ruck)
- Hooge Burch (IF ?, if possible).

Subtasks D:

To be further discussed in Adana at Annex 13 meeting.

Subtask E:

Send economic values to *Bert Gysen* by the end of January 2002 (reminder from Bert end of December).
Evaluation until end of March.

AOB

Proposal should be discussed regarding an annex on optimization of BHE and BHE systems, incl. thermal response testing, thermally enhanced fills, etc.
(might be a joint annex under ECES together with Heat Pumps and Geothermal)

An international summer school on geothermal energy was held in Bad Urach, Germany, in September 2001, including a 3-day course on geothermal heat pumps. The course material will be available on-line on the homepage of the institute; the table of contents already can be seen under:
http://www.uni-giessen.de/~gg1068/html/literatur___tagungsberichte.html

Next meeting (XM 9)

In conjunction with Annex 13 in Sweden (probably Lund), either week 15/2002 or, if necessary, week 12/2002.

The Operating Agent thanked GTN GmbH for the perfect organization and hospitality in Neubrandenburg.
The session was closed 18:10.

19:30 Diner hosted by GTN GmbH at lake Tollense, Neubrandenburg

9.11.2001

8:30 visit to the existing components of the planned Neubrandenburg ATES project:

- Existing geothermal heating central (currently out of operation, peak boilers used for district heating), with large plate heat exchanger, absorption heat pump, DH-equipment.
- Wellhead building 1
- Gas and steam heat and power co-generation plant with 2 gas turbines, 1 steam turbine (steam produced by gas turbine exhaust), total electric power output ca. 90 MWel and heat output ca. 80 MWth. Heat from the power plant in summertime will be used for loading the store.

11.00 Meeting in the conference room of the power plant control building, discussion of the German R&D-project, see attached minutes (in German). Closing ca. 12:30.

Appendix B

Minutes of the 9th Expert´s Meeting in IEA ECES Annex 12 High Temperature UTES

15.-16.4.2002

Participants:
Frank Cruickshanks, Environment Canada, Halifax, CAN
Göran Hellström, Lund University, Lund, S
Guido Knoche, ISWA, University of Stuttgart, D
Manfred Reuß, ZAE Bayern, München, D
Burkhard Sanner, IAG, University of Gießen, D
Thomas Schmidt, ITW, University of Stuttgart, D
on 16.4.2002 additionally:
Olof Andersson, Sweco, Malmö, S
Mats Egard, Sycon, Malmö, S

Begin 15.4.2002, 13:00
SWECO offices, Geijersgatan, Malmö, Sweden

Country status

Country	Status	Participant
Belgium	member	VITO
Canada	observer	Environment Canada
Germany	member	FZ Juelich / Giessen University
(Netherlands	„assitant“	IF Technology)
Sweden	member	FORSAS / TU Lund

Monitoring (general update and discussion)

NSU

Heat charged/discharged: data acquisition problems in charging phase twice
1) flow meter monitoring card in PC broke down in late summer 2000
2) disconnetion of sensors during construction of the extension

Temperatures fluid in/out, ground temperatures.
In summer 2002 it is planned to load the new storage extension only, to harmonize temperatures with the „old“ store which is already warm.

Discussion on TED-measurements made by Manfred Reuss, Rb and thermal conductivity

Rostock

Energy flows in-out:
In winter 2000/01 there were problems with the heat pump, and thus low discharge; in winter 2001/02 this was solved, and discharge is much higher.

Fluid temperatures in-out
Very impressive thermal front tilting (buoyancy flow) with peak in July 2001.

Reichstag

At the time of the meeting, all relevant components that contribute to loading and discharging both stores have been completed. Due to the late completion of the cooling tower for cold storage (on top of Paul-Löbe-Haus) and the relatively warm March, no cold storage could be started in winter 2001/02. The cold storage mode only was tested for a few hours to check the hydraulic circuit.

Also the second combined heat and power plant (in Paul-Löbe-Haus) has been completed, and thus in summer 2002 loading of the heat store will be done with full load and high temperature (70 °C) as planned. Until now only part of the capacity was operational, resulting in lower loading temperature on the order of 40 °C.

The first full heat storage and heat retrieval circuit will be completed in spring 2003, the first cold storage and cold production cycle in autumn 2003, after 3 years of cooling in summertime and the respective heating of the cold storage aquifer.

Attenkirchen

Construction of the solar system was finished in Aug. 2001
Construction of storage in 2 phases:

- underground water tank installed in early summer 2001
- drilling of boreholes in autumn 2001 (90 BHE)

Connection pipes postponed to spring 2002 due to early winter
Equipment in heating central finished end of 2001
Installation of system control in early 2002
Currently 2 houses finished and heated since March 2002

Anneberg

20-30 % more expensive than planned: storage and solar collectors are as planned, distribution net higher as calculated.
In operation since march 2002.

Malmö

District heating is partly supplied by heat from waste incineration. This is also available in summertime, when DH load is lower than supply from waste incineration. The idea is to use part of the summer waste heat and store it at high temperature (around 100 °C, if possible). Aquifers at ca. 400-450 m depth in Sandstone layer (Lunda sandstone), 50 MW heat output, with 2 x 18 wells!
Alternatives: BTES conventional and „leaking“, shallow ATES.

TESSAS Mol

Drilling under way, already almost finished.

Canada

Thermal Response Test Cross Section through Halifax in planning

Hawthorn Village in Mahone Bay, NS

HT-BTES with ca. 80 houses, medical centre, etc. in realisation, with solar thermal for loading; total system should have at least 50 % solar fraction.

Quinpool Towers, Halifax, NS

Residential complex, flats/apartments
1100 m^3 pilot store, 4 holes, 3 m distance 120 m depth, Thermal response test; storage operated at 50 °C. Planned to be enlarged to ca. 32 boreholes. Solar collectors and/or waste heat are planned to be used as the heat source.

Report Format:
For the final freport, try to present the monitored data in diagramms following the example from ITW. A section with new projects under construction, following the project report format used in the phase-1-report, will be added to the final report; please provide the data to Burkhard Sanner.

Subtasks

B1 Monitoring of thermal performance

Recovery factor not possible to give in all of the new plants; only Rostock is in a kind of steady operational phase.
Definition: Recovery factor = annual recovered energy / annual charged energy

Suggestion from Manfred Reuss: Calculate turnover factor, to give a measure of the use of the store:
Definition: Turnover factor = Annual charging energy / storage capacity
Storage capacity:
Capacity = volume x specific heat capacity x temperature difference
Volume

- BTES: horizontal cross-sectional area ascribed to each borehole x number of boreholes x active borehole depth x α_v
- ATES: horizontal influence area around the warm well as calculated by thermal front tracking (e.g. with Conflow), taking 5th year values x aquifer thickness

Specific heat capacity

- BTES: EED database
- ATES: saturated ground values acc. EED-database

Temperature difference

- ATES + BTES: Temperature difference = Maximum charging temperature - Minimum possible recovery temperature

B2 Monitoring of environmental and chemical aspects

No report, as W. Ruck was not present (excused). Only 3 ATES; two of them chemically monitored by W. Ruck. Individual scheme for each project

B4 Control issues, operating strategies

Describe possible modes of operation, based in the system integration
Describe design operational strategies and actual operation experience
Describe control mechanisms to achieve these operation
Manfred develops a format

C ATES test

Test rig used in Stuttgart and 3 external sites: Nijmegen, Pellworm, Frankfurt a.M.

Saturation indices were calculated using Phreeque; also Pellworm had a positive value, while no precipitation occurred (natural inhibitors?).
Standard Procedure was suggested to compare results of different sites:

- 24 h
- 8 kg/min (0.48 m^3/h)
- 10 K temperature steps;

then a longer experiment to confirm the behaviour in the critical temperature range.

D BTES ground parameter investigations and BHE optimization

New: Hydraulic investigation in addition to TRT in the „Scandinavian" type wells (in hard rock, open, not grouted).
For the report, take a summary of the relevant Annex 13 draft documents (by Gehlin/Spitler and Hellström, respectively).

E abandoned

F Economy

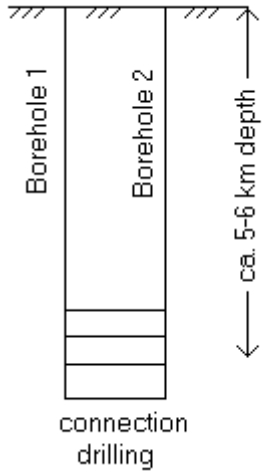
Values from B. Gysen were shown. The problem of comparison of cost between different system concepts and storage types was clearly addressed. An agreement was reached that no comparison tables should be prepared, but the economic data will be presented by project and in the context of the individual project only.

Geothermal report
given by Mats Egard, Sycon Energikonsult

Hydrogeothermal doublet for district heating:

- total annual heat load ca. 2500 GWh
- geothermal production rate 300-350 m^3/h
- geothermal output ca. 20 MW and 100-130 GWh
- doublet 2 km deep, deviated holes
- expected ca. 60 °C water, from Rhetian sandstone (Lias) or deeper (Triassic)
- Direct HX and Absorption HP, driven by biomass-fired plant

Information from old oil exploration and new seismic measurement (Vibroseis) has been compiled; common activities with Denmark, DONG is involved in both.
Operation should commence fall 2004. Cost is estimated to 180-200 Mkr; 44 % of it for drilling etc.



Future plans (see sketch):
6 km deep holes, with horizontal drilling by Wassara to connect the holes and thus to build a heat exchanger; 150 °C rock temperature expected, somewhen in 20??

Next steps

Providing the data as discussed in the subtasks by June 2002 to the OA. Editing of final report over summer break. Next meeting to review draft of final report: October 2002 (Germany)

Meeting closed 16.4.2002, 17:00