

Efficient usage of waste heat by applying a seasonal energy storage (BTES) at ITT Water & Wastewater AB, Emmaboda, Sweden

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ABSTRACT

ITT W&W is a world leading manufacturer of submersible pumps and mixers. The Emmaboda plant contains a foundry, an electric motor workshop and several product workshops. The foundry generates a large amount of waste heat that is disposed to the atmosphere at all times. In order to utilize the waste heat to a larger extent than at current, high temperature borehole storage (HT-BTES) is under development. In this paper the designing results from the design of the storage system are described.

1. INTRODUCTION

The foundry at ITT W&W encounters a large consumption of electricity with a high waste heat potential. The plant is run some 4 400 hours a year and approx. 10 GWh of heat, is disposed to the atmosphere over a year. Even if some already is recovered at winter time, the recovery can be substantially increased by applying a high temperature borehole seasonal storage (HT-BTES). Such a system will replace most of the externally supplied district heating (DH) that is currently used for space heating. By using a storage system, combined with heat pumps, ITT W&W expects to increase the recovery of waste heat to such a level that the dependence of DH will be reduced to a minimum.

Economical support for the project has been granted by KLIMP (a regional granting of projects reducing the climate change). At present the project is preliminary designed and tender documents for construction has been worked out.

2. SYSTEM DESCRIPTION

As shown in the figure 1, the ovens are currently chilled in two steps. In first step heat from the ovens is transferred to the local DH system through HEX 2. In the second step the ovens are chilled by a cooling tower through HEX 3. In between HEX 3 and the cooling tower there is a water basin that evens out the temperature swings from the ovens. The water basin also serves as a cooling medium for number of other minor processes. (These functions are not shown in the figure). A major part of the heat needed for space heating at the factory is currently supplied by external district heating through HEX 1.

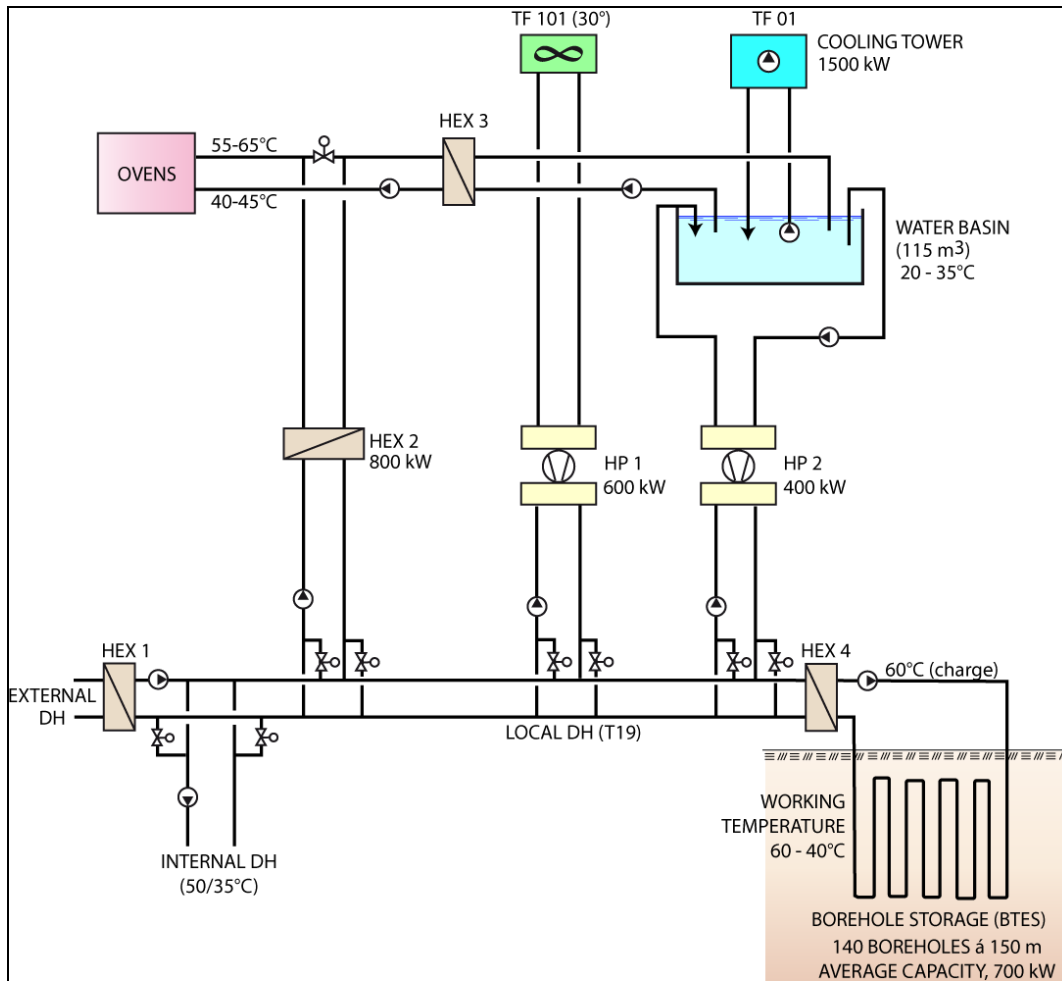


Figure 1: Predesigned system for a better utilization of waste heat

To allow a better waste heat recovery the existing system is designed to have the following new components (see figure 1).

- A heat pump (HP1) for utilization of heat from the cooling tunnel (TF101). The heat pump (600 kW) will lift the temperature from +30-35 to +60-65°C and produce some 2 500 MWh of heat annually at a COP of 3, 6.
- A heat pump (HP2) for utilization of heat from the water basin. The heat pump (400 kW) will lift the temperature from +20-35 to +60-65 °C and produce around 2 000 MWh of heat at a COP of 4, 2.
- Borehole thermal energy storage (BTES) for combined seasonal and short term storage of waste heat. The storage is designed for charge of 3 800 MWh annually at a temperature around +60-65°C (maximum +70°C). The storage temperature after recovery is +40°C.

The optimal recovery capacity from the ovens to the internal DH will be in the order of 1 500 kW. By adding the BTES system at a discharging mode the capacity will increase to 2 200 kW.

3. FUNCTIONAL DESCRIPTION

The connections to the internal DH are such that heat can be delivered to both the supply and the return pipe of the DH net. The primary source will always be the direct heat recovery from the ovens through HEX2, followed by the heat pumps for additional heat. All surplus heat, not used in the internal DH, will be stored in BTES at the highest temperature level possible (max. +70°C).

Discharging the storage will always be done to the return pipe. With such a connection only peak loads, if any, can be covered by the external DH through HEX1.

The BTES will have separate sections with an inner “hot centre” and an outer “less hot mantle”. The reason for this design is to adjust the production temperature to the actual temperature demand and to occasionally allow a short term storage function located to the “hot centre”.

4. BASIS FOR SYSTEM DESIGN

The two latest years, that has been mild winters, the internal DH system has distributed approx. 8 000 MWh of heat annually. Of this some 5 000 MWh was supplied by the external DH system. The maximum heat load demand is around 3 800 kW at -18°C, see figure 2. This load is required during night time when there is no supply of waste heat from the foundry. With the planned heat recovery system the loads can be met down to a temperature of approx. -10°C.

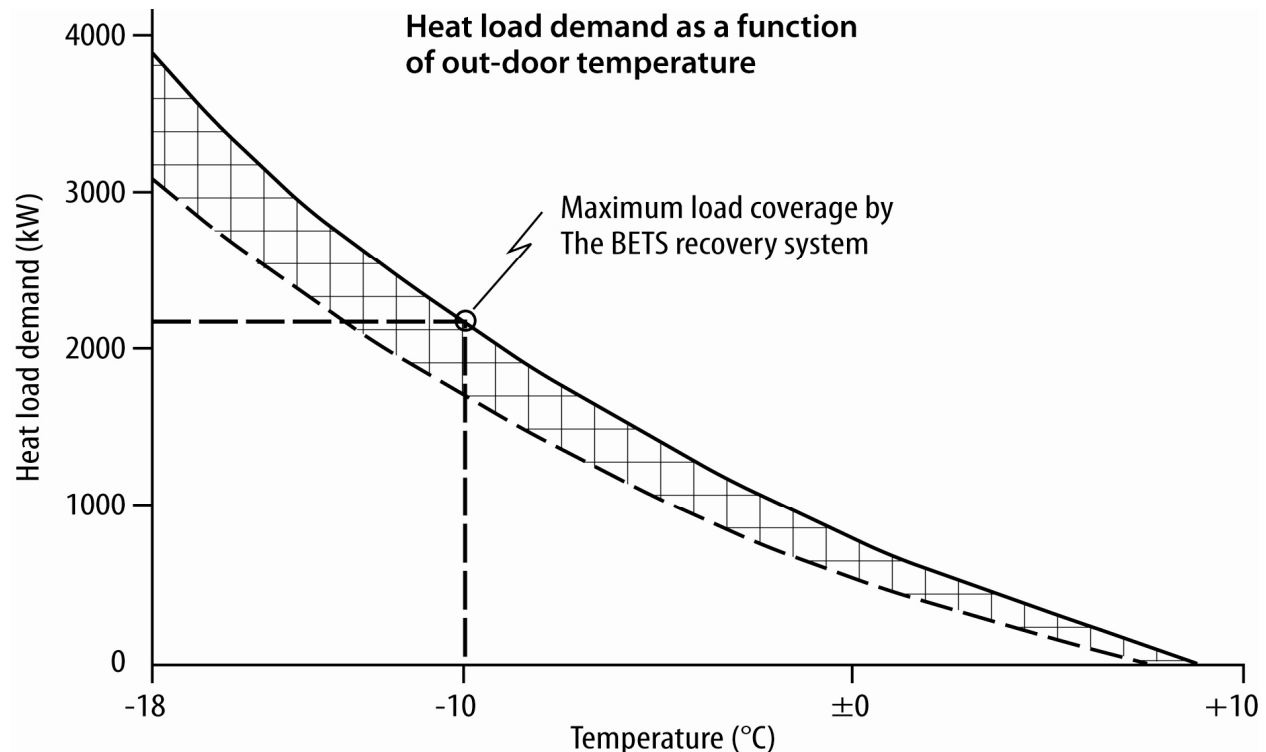


Figure 2: Heat load demand derived from delivery from the external DH (HEX1), based on plots of measured data from the years 2004-2007. Maximum values express a situation without any internal heat recovery from HEX2.

Measurements from 2006-2007 indicate that the supply temperature in the internal DH system is at around $+55^{\circ}\text{C}$ during the coldest days of the winter. However, most of the winter season it is kept below $+45^{\circ}\text{C}$, see figure 3.

The return temperature is in general some 10°C lower and kept within the frame of $+30\text{-}40^{\circ}\text{C}$. This indicates that the BTES easily can produce heat down to at least $+40^{\circ}\text{C}$, maybe lower. These are all temperatures that can be expected to function with the planned heat recovery system.

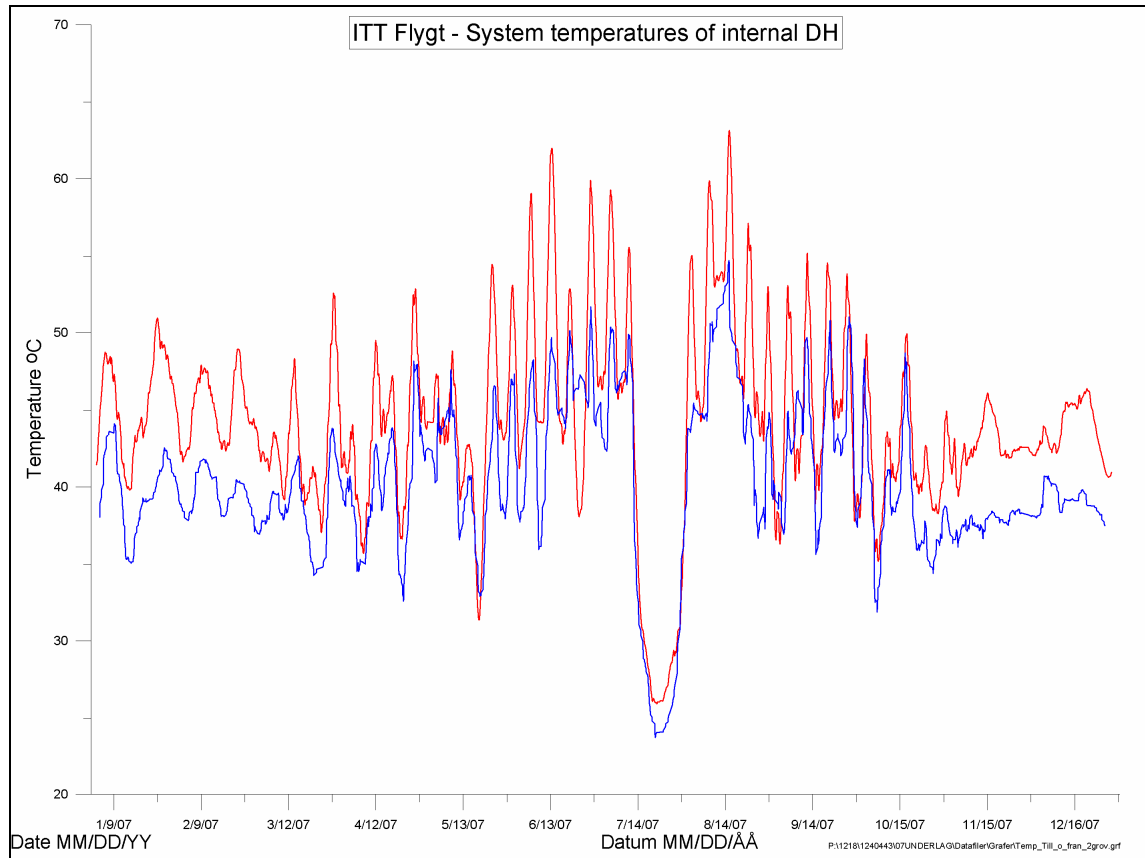


Figure 3: Supply and return temperatures in the internal district heating system during one full year. The high temperature peaks during the summer is due to dumping of heat to the DH without being used.

5. BASIS FOR BTES DESIGN

Since the geological conditions are similar all over the factory area, the only criteria are (a) that the storage should be located close to the existing local DH system, (b) the storage will not interfere with the factory activities during construction, and (c) that it will not interfere with future building plans.

From these criteria the borehole field has been located to a “recreation” area close to a dam, see figure 4. The ground here is flat and is partly a lawn and partly an asphalted bus parking place.

The hydro-geological conditions at site have been documented by two investigation boreholes placed at each side of the site (distance between approx. 50 m). The main results from these drillings are:

- The soil consists of 7-8 m of glacial till
- The rock types, down to a depth of 200 m, consists of diorite (55 %) gneiss and granites (25 %) and amphibolites (20 %)
- The upper 2-3 m of the rock is fractured and unstable, which means that casing has to be drilled to some 12 m.
- Ground water yielding zones were penetrated at a depth of 35-40 m in both holes and at 70 m in one hole. However, the hydraulic conductivity is low, approx. $1-2 \times 10^{-6}$ m/s.
- The ground water level in rock is approx. 2 m below surface.

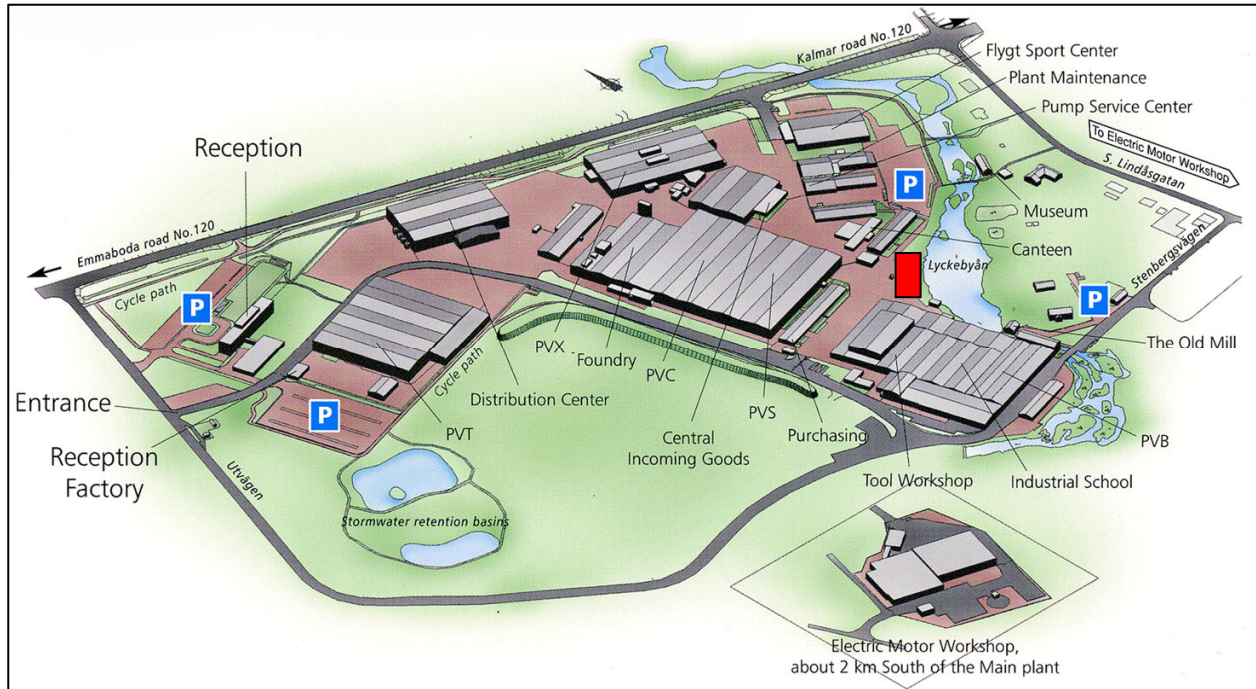


Figure 4: The ITT industrial area Emmaboda with the location of the BTES site (red square)

The thermal properties have been measured by thermal response tests (TRT) in both the test holes. The distance between the two holes is approx 50 m and they were both drilled to 200 m. The measurements show the following results:

- The ambient temperature in the rock is $+8^{\circ}\text{C}$ and the geothermal gradient is $1,5^{\circ}\text{C}/100\text{ m}$.
- The thermal conductivity of the rock mass is $3,2\text{ W/m,K}$ in average ($3,0$ and $3,4$)
- The thermal resistance with water filled boreholes and single U-pipes is $0,06\text{ K(W/m)}$

6. PRELIMINARY BTES DESIGN

Measurements have shown that there will be around approx. 3 000 MWh surplus heat that can be stored during the summer season (May-September). During autumn, winter and spring there is another 800 MWh of heat that can be supplied to the BTES system, mainly with on short term

basis. Hence, some 3 800 MWh of excess heat is estimated to be the potential for storage of which 3 000 MWh is seasonal. Of this heat approx. 1 500 MWh is generated by the heat pumps.

For the design of number of boreholes, depth and distance between holes at a given surface area the simulation model EED (Earth Energy Design) has been used. The simulations preliminary indicate that 140 boreholes á 150 m with a rectangular shape and a hole distance of 5 m is optimal for a storage of 3 000 MWh. The additional 800 MWh for short term storage during the winter season does not take any extra holes. This energy lies “on top” with a higher temperature quality and less losses. Taken into account that the average time for the seasonal storage is six months, and that the storage working temperature is +60/40°C, the storage losses is estimated to be in the order 1 200 MWh (68, 5%). Hence, 2 600 MWh will be recovered and utilized.

According to the calculations the storage will be able to deliver a load capacity of some 1 100 kW at a maximum (early winter and short term cycles). However, at the end of the space heating season, the capacity may drop down to 100 kW at the lowest (short term cycles excluded). The average load capacity during the winter season is approx. 700 kW.

Due to the high temperature and to achieve a high thermal performance, a specially constructed borehole heat exchanger (BHE) will be used. The BHE will consist of a single 90 mm centralized plastic tube inserted into a 115 mm borehole. The tube material will be PEX, a plastic material that keep its strength at temperatures up to at least +80°C. In the simulations with EED, a thermal borehole resistance of 0, 01 K/(W/m) has been assumed for this type of BHE. A prototype will be tested before solution can be used.

In the design it has also been considered to have a reversed flow possibility over the BHE. By charging from beneath and upwards and discharging with a reversed flow direction, the performance is expected to be optimal from a temperature point of view.

7. PRELIMINARY ECONOMICS

The investment cost for the total system has been calculated to approx. 10, 6 Million SEK split into the following items:

- Heat pump HP1, installation and side equipments included, 1 700 Thousand SEK
- Heat pump HP2, installation and side equipments included, 1 200 Thousand SEK
- BTES, boreholes and piping system, heat exchanger included, 6 500 Thousand SEK
- Controlling system and power supply, 1 200 Thousand SEK

The investment is estimated to reduce the dependence of external DH with 4 800 MWh annually. Of this reduction the BTES will supply 2 600, while 2 200 will be produced directly by the two heat pumps.

The economic value of the savings is currently 2 250 Thousand SEK annually (470 SEK/MWh). For running the system, mainly the heat pumps, 650 MWh of electricity is used. The present annual cost for this is 300 Thousand SEK (450 SEK/MWh). Based on these figures, the annual

net savings will be 1 950 Thousand SEK. This indicates a straight pay back time of 4 years (grants included) or 5, 5 years (grants excluded).

8. ENVIRONMENTAL ISSUES

The environmental evaluation is based on the following technical properties of the system:

- The heat carrier between the BTES and the local district heating consists of water in closed loop that has no physical contact to other flowing media in system except the ground water in the bedrock.
- The water will have no additives and will consist of local tap water.
- The flow will be regulated by one or several frequency controlled circulation pumps. The pressure will be low, approx. 2 bar as a maximum.
- The rock around the boreholes will be heated up to maximum +70°C. The highest temperatures will occur close to each one of the boreholes. The highest average temperature of rock mass will be +60°C fully charged, and +40°C as lowest when fully discharged.

During construction a temporary lowering of the ground water in the rock is expected. However, the rock has a low permeability and the disturbance will therefore be limited to a narrow area.

The tap water used as heat carrier is oxidized and may to some extent mix with a slightly reduced ground water that occurs in fractured part of the rock. If so, iron and manganese in solution may precipitate in the fissures and clog these. However, the amount of precipitates is estimated to be very low, but on a very long term, the permeability of the rock may be locally decreased.

The type of borehole heat exchanger used will allow hot water to have direct contact with the borehole walls. In theory, some of the minerals would get into solution in the water. However, results from IEA research on this subject clearly indicate that the risk for such processes is very low with actual types of rocks and temperatures (Snijders 1995).

The IEA research also shows that an increase of temperature up to +70°C will kill all bacteria in the centre of the storage. Along the sides with temperatures of +45°C and less, the micro fauna will adopt with new species of mainly iron-, sulphur-, methane-, and nitrogen bacteria. However, an increased temperature will not lead to an increased growth of bacteria since growth is mainly controlled by an increased access to nutrients, such as organic coal. It shall also be considered that the natural bacteria fauna will be return back to normal once the storage is shut down and the rock is slowly recovered to ambient temperature.

Heat that is stored in the rock mass can be transported away with the flow of ground water. The two investigation holes suggest that there are a couple of fracture zones that in theory may displace some of the heat being stored. However, based on the fact that the ground water gradient is very small (approx. 1/100), and that the hydraulic conductivity of the bedrock is low (10^{-6} m/s), no spreading of heat is expected. (In theory the flow of ground water is less than 0, 5 m/year).

The calculated losses from the storage is 1 200 MWh annually. This heat will mainly reach the surface at storage area, approx. 5 000 m². Theoretically estimated the heat losses at surface will be in the order of 30 W/m². This is about 500 times more than the natural heat flux from the

underground ($0,06 \text{ W/m}^2$) caused by the geothermal gradient. A consequence of the increased heat flux would be that the surface will be unfrozen during winter and that snow will be melted quicker than in the surroundings. The area with grass will potentially have an increased time of growing and may even grow in the winter. The nearby dam will probably not be affected at all since heat that leaks out here will mix and disappear with the flow of water through the dam.

9. CONCLUSIVE REMARKS

Using HT-BTES for seasonal storage has been a subject for research and development within IEA since early 1980: ties. At present the technology is fairly well established in a number of countries (Sanner 1999). In the design of this project experiences has been gained from a former equal project in Luleå (Nordell 1994), especially concerning the BTES part.

The concept has also been used in an EU-project as “case study” on how shallow geothermal can be applied in the industry (IGEIA). As such it demonstrates how waste heat can be utilized by the usage of Underground Thermal Energy Storage (UTES). The potential for such systems is estimated be at least 10 TWh/years only in Sweden (Andersson et al 2008).

From an economic point of view, the BTES technology takes a large investment. However, since the running cost is low, the pay-back time is fairly low. It shall also be considered that the BTES systems normally have long life time and that the maintenance cost is expected to be low.

The environmental studies indicate that there are only limited local environmental impacts to be expected installing and operate a BTES system. Instead, the system would be of benefit for the environment by saving thermal energy that can be used else where. In the decision for having subsidies from KLIMP, the savings was estimated to reduce the emission of carbon dioxide with approx. 1 500 tons. In fact this was one of the main criteria for having the grant. Another criterion was that ITT Flygt is using “green” electricity.

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