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DGE-ROLLOUT

Options for energy cascading and heat demand management at TRUDI

WP T3 Product Optimization - Deliverable 2.2

Arianna Passamonti (Fraunhofer IEG)

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Introduction

To examine the options for energy cascading and heat demand at the TRUDI site in Bochum, an analysis on seasonal heat source, district heating and heat demand at the site was performed. Subsequently, energy cascading options and efficient heat demand strategies were highlighted.

Concerning the energy cascading, the solutions have been studied at the high temperature heat pump scale, at the local pilot plant scale of TRUDI and at the site scale of the Querenburg district.

Efficient heat demand management includes considerations on heat pump partial load along with peak load and base load usage of the technology and optimization in terms of electricity costs.

Seasonal heat source, district heating, heat demand at TRUDI

Goal of the DGE-Rollout project at the TRUDI test site in Bochum is to install a geothermal high temperature heat pump (HTHP) connected to the district heating (DH) grid. The overall system is a pilot project that will prove the feasibility of the exploitation of unused flooded mine galleries as heat source and seasonal storage for heat production through the HTHP technology.

The shallow submerged coal mine, situated at the premises of the Fraunhofer IEG offices at the TRUDI test site, has an expected water volume of c.a. 20 000 m^3, as shown in *Table 1*. With the intent of optimally exploit the heat reservoir, the best HTHP solution is chosen to be of 500 kW with high modulation.

Table 1. Data from mine seasonal thermal energy storage, heat source of the HTHP

Mine galleries data	
Mine depth [m b.g.l.]	75
Groundwater level [m b.g.l.]	23
Unheated water T [°C]	12
Years of production	1954 - 1957
Coal extracted [t]	37.043
Coal extracted [m³] *	27.439

Source: Hahn et al., 2020

Cold source volume (Vc) [m³]	19.207

Assumption: 70% of the total volume is flooded, considering: water level, shafts, drifts.
*coal density: 1,35 g/cm³

Along with the complexity in terms of heat source, considering that the utilization of flooded mine galleries as heat source has been very seldomly implemented, a challenging element for the state of the art of the heat pump technology is to reach the needed supply temperature.

The district heating grid of Bochum South and the branch of the RUB, at which the heat pump will be connected, requires between 80°C and 120°C of pressurized water supply temperature, varying with the ambient air temperature as reported in *Fig.1*:

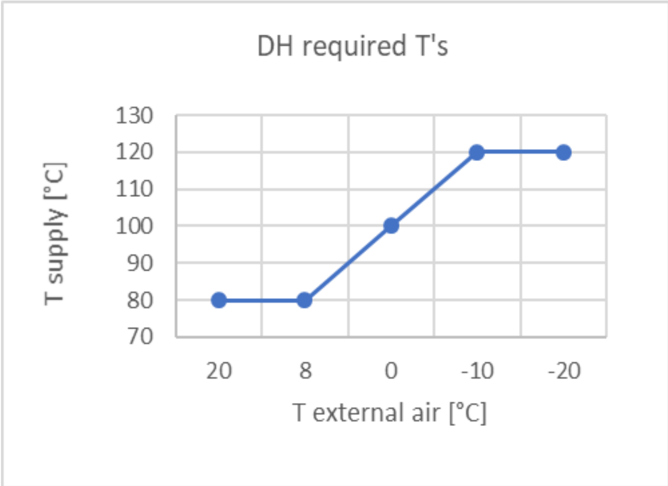

Figure 1. Variation of DH required temperature with the external ambient air temperature

Therefore, given the degree of difficulty of the plant design in terms of heat source and HTHP technology, the system goal is not strictly linked to the heat demand of a specific customer but it is to prove the viability of such an innovative technology and to exploit the source in the best possible way, in the district heating context.

Specified the background information, to better understand the framework in which the heat pump will be installed and the cascading solutions, a more precise analysis on the heat demand of the TRUDI area and on the district heating grid was performed.

The current heat demand of the buildings situated near the TRUDI site as kWh/y for each 100 m^2 of area, is showed in the following image *(Fig.2)*:

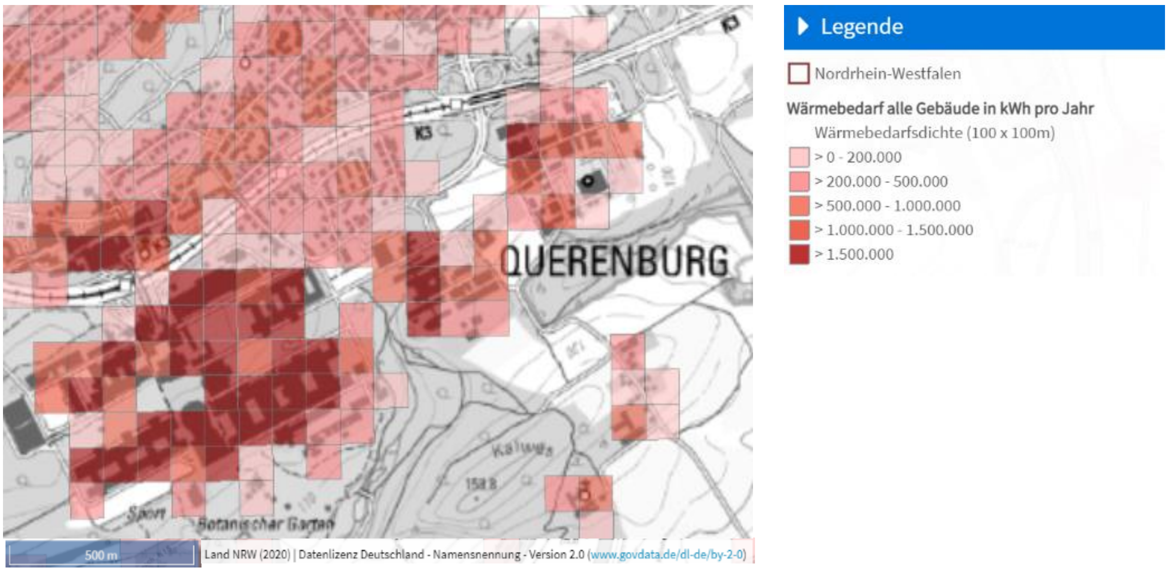

Figure 2. Heat demand near TRUDI site. Source: Energieatlas NRW

In the district of Querenburg situated at Bochum south, where Fraunhofer IEG is located (ex Geothermie Zentrum Bochum buildings) most of the heat demand is required by the Ruhr-Universität Bochum (RUB). In addition, the existing buildings of offices and laboratories of Fraunhofer IEG have an annual heat demand of 165 MWh that is supplied by locally employed heat pumps (140 kW), not connected to the district heating. The development of new buildings, according to the planning as of today, will allow to roughly double the current institute's heat demand.

From 2018, the district heating network of the *unique Wärme GmbH & Co. KG*, supplies the RUB campus with around 5 600 employees and 43 000 students, in addition to 4 800 rented flats, 760 homes and 115 other customers of the surrounding Querenburg neighborhood. It is made of three gas fired boilers and two CHP units. The plant can generate a total thermal output of about 9 MW.

Energy cascading options at TRUDI

In this context, there are different options for energy cascading. They can be analyzed at different scales, namely: at the HTHP scale, at the local pilot plant scale (TRUDI), and at the site scale (Querenburg district).

At the HTHP level considerations can be made on the chosen heat pump model itself. In order to be able to supply water up to 120°C starting from a minimum mine water temperature of 12°C, the most promising solution is in fact a cascading system. The preferred heat pump, is made of two independent stages running with R717 and R600, respectively. The temperature levels will be a low one from 12°C to 60 °C and a high temperature level from 60°C to 120°C. In this way it will be possible to use one or two stages according to the temperature of the mine as well as to the district heating needs.

At the local pilot plant scale, the heat cascading from different sources is developed by means of different temperature ranges present in the system. Concentrated solar thermal energy at the temperature range of 100-200°C is used to heat up the mine seasonal thermal energy storage, during the summer. The storage or heat pump source, will be at a temperature between 60°C and 10°C. The temperature will increase during the summer and decrease with the proceeding of the heating season and with the heat pump usage. In addition, the heat pump will be working with this source to produce heat from 80°C to 120°C *(Fig. 3)*.

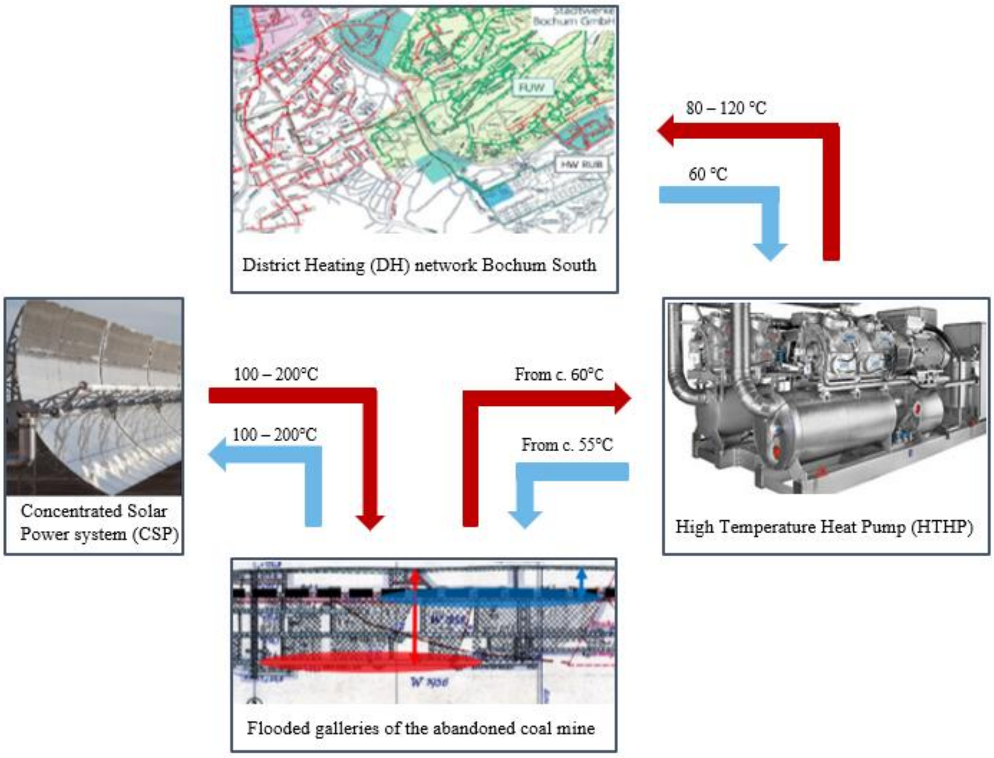

Figure 3. Overall system concept of DGE-Rollout pilot plant at TRUDI demo site in Bochum (local pilot plant scale)

For future developments at the TRUDI test facilities, further heat exploitation will be possible with the drilling of a deeper well as heat source integration. With a depth greater than about 1500 m, it will be possible to obtain water at a constant temperature between 40°C and 60°C, throughout the different seasons.

The overall system can be therefore seen as cascading between different temperature levels.

Further considerations of heat cascading at the local pilot plant scale can be described along with the current draft of piping and instrumentation diagram *(Fig.4)*. On the preliminary study, that will be further modified and developed, are presented different options for heat injection, and extraction, as well as testing plans and heat recovery. Important to note that there will be a “mine” tank, that is a water tank used as storage in parallel to the mine. This will allow to store heat with the main purpose of testing the heat pump over a period of 8 hours.

During heat injection, i.e. heat transfer to the mine storage or to the “mine” tank from different sources, the hydraulic scheme is planned to have connections from the CSP and the district heating towards both mine and “mine” tank.

During heat extraction, i.e. heat transfer from mine or “mine” tank to the district heating. The possible options are direct extraction from mine or “mine” tank to the district heating when the temperature of the mine or the tank will be at the same level of the one required by the district heating. Or indirect extraction by means of the HTHP exploitation, still from the considered sources.

A high temperature heat exchanger is planned for direct connection to the district heating as well as dry coolers for heat dissipation during the test phases.

Furthermore, the hydraulic system is arranged to integrate the different sources in order to exploit their waste heat.

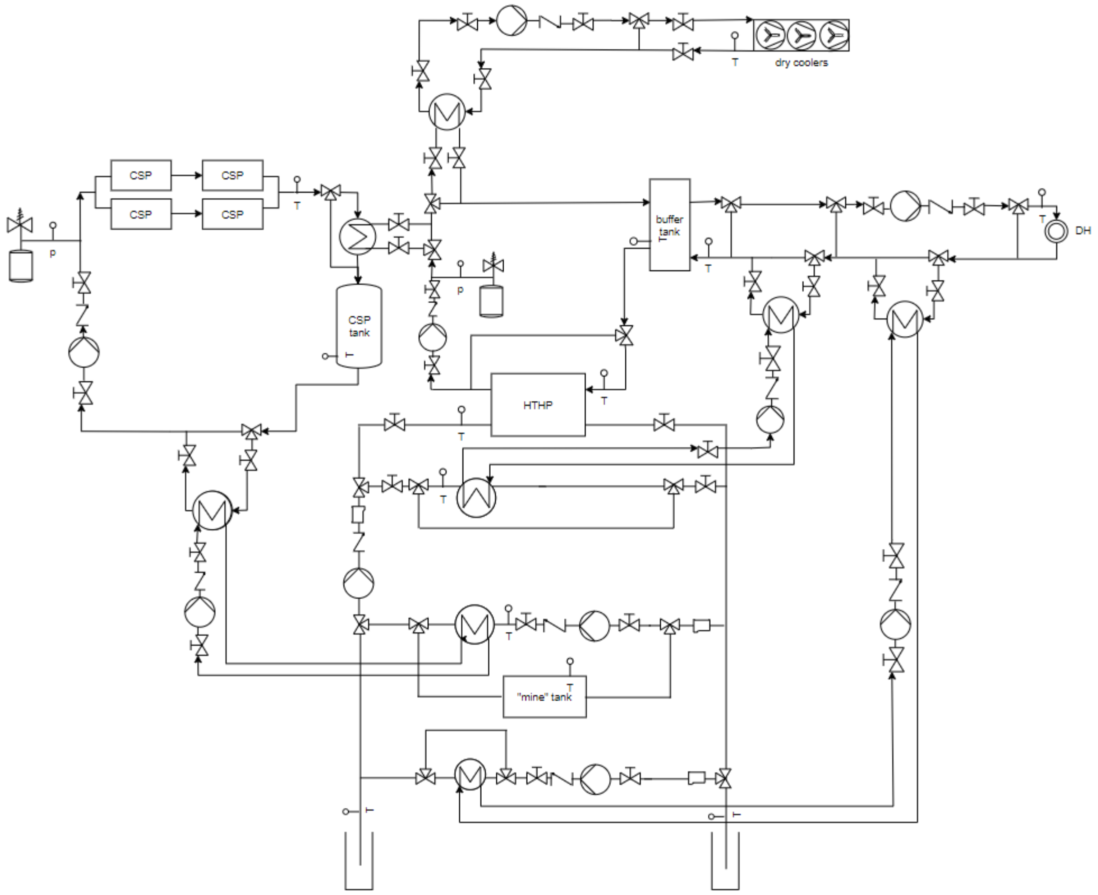

Figure 4. Piping and instrumentation (P&ID) current draft

At the site scale, different options of cascading from mid-low temperature sources are considered. These are: the waste heat from the CHP plants that currently supply the district heating, the waste heat from agriculture processes and the district heating return.

Further discussion with the utility companies are in place to verify the feasibility of such options.

Efficient heat demand management at TRUDI

The heat pump will not be directly connected to a particular building but integrated in the district heating grid. At the HTHP level, the demand is managed in terms of precisely following the supply temperature curve, according to the external ambient temperature. The heat pump is also able to modulate down to the 15% of the total power to allow maximum flexibility from the mine and towards the district heating.

After the validation of the mine behavior, its physical heat capacity, and testing of the mine, it will be possible to evaluate precisely the amount of heat that the heat pump will be able to supply to the consumer, with eventual considerations of need for further heat sources. After these deliberations, it will be possible to run the heat pump as integration source for the district heating both for base load or peak. It should be considered that the amount of heat that this heat pump will provide for the district heating is of a different order of magnitude compared to the overall grid. This will allow flexibility in the heat supply and the possibility to fully test the overall system of concentrated solar energy, mine thermal energy storage and high temperature heat pump.

After the drilling of the deeper well at the TRUDI test site, due to its constant production, a management option would be to exploit this last well as base load and the mine source as peak load.

In addition, the buffer tanks planned in the system will also be exploited to optimize the heat production with respect to the cost of the electricity. In particular, the heat pump will be running when there is lower cost of electricity, and the heat stored in a tank to be then used when there is higher demand.

Conclusions

The description of the plant characteristics and heat demand near the TRUDI site led to considerations on the scope of the pilot site: to prove the feasibility of the integration of seasonal mine thermal energy storage with high temperature heat pump. In this context, options of cascading system on different scale levels are reported as well as heat demand management.

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PROJECT PARTNERS

PROJECT SUB-PARTNERS

MORE INFORMATION

Dr Martin Salamon (Project Manager)

Martin.Salamon@gd.nrw.de

+49 2151 897 445

www.nweurope.eu/DGE-Rollout

@DGE–ROLLOUT

SUPPORTED BY

europiZe UG

Dr Daniel Zerweck

+49 176 6251 5841

www.europize.eu