Interreg North-West Europe
DGE-ROLLOUT

Tested cascading schemes

WP I Invest - Deliverable I 1.3.1

Arianna Passamonti (Fraunhofer IEG)

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Introduction

Deliverable I 1.3.1 of the DGE-Rollout “Tested cascading schemes” is defined as: number of tested multi-level cascading strategies and this should be equal to 3.

The deliverable, as part of the activity I 1.3 “Application of cascading strategies” is strictly linked to Deliverable T3 2.2 of work package product optimization.

A summary of Deliverable T3 2.2 is reported and in particular the considered cascading schemes that are presented on three scales: high temperature heat pump (HTHP) scale, local pilot plant scale (TRUDI), and site scale (Querenburg district).

Proof of the testing is then reported for the three different scales in the following sections.

Summary of Deliverable T3 2.2

In the part of the deliverable dedicated to options for energy cascading and heat demand management at the TRUDI test site, the cascading concerning the development of WP I was analyzed.

Different options for energy cascading were considered 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 chosen solution is in fact a cascading system. The 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. 1).

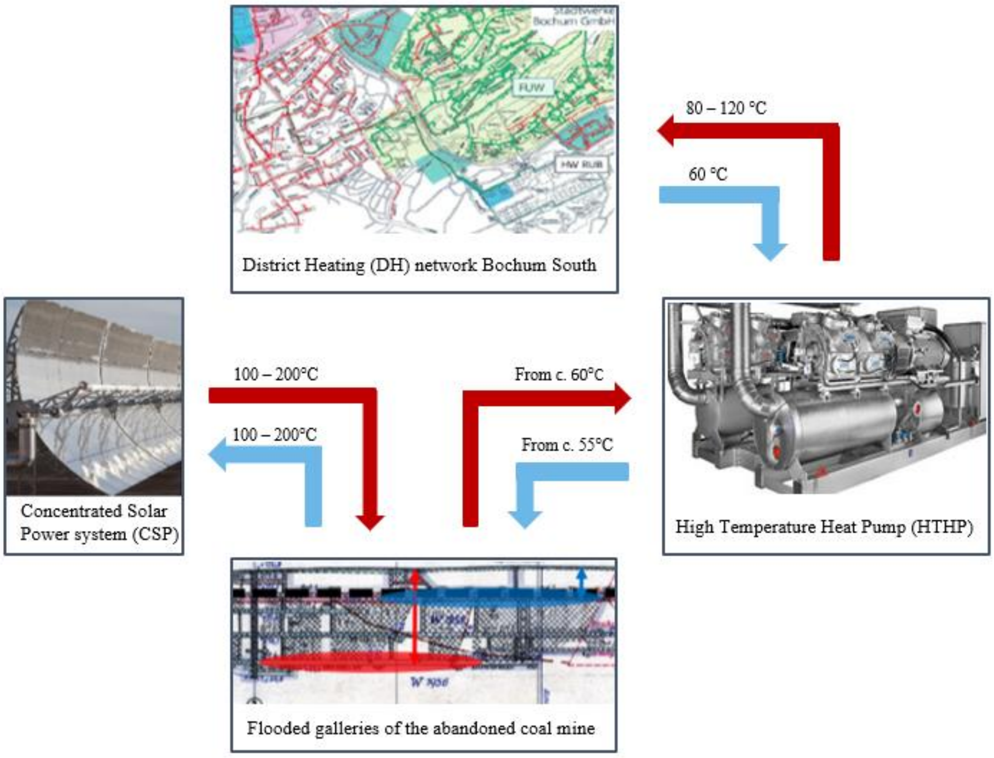

FIGURE 1. Overall system concept of DGE-Rollout pilot plant at TRUDI demo site in Bochum (local pilot plant scale)

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 piping and instrumentation diagram (Fig.2). There, 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.

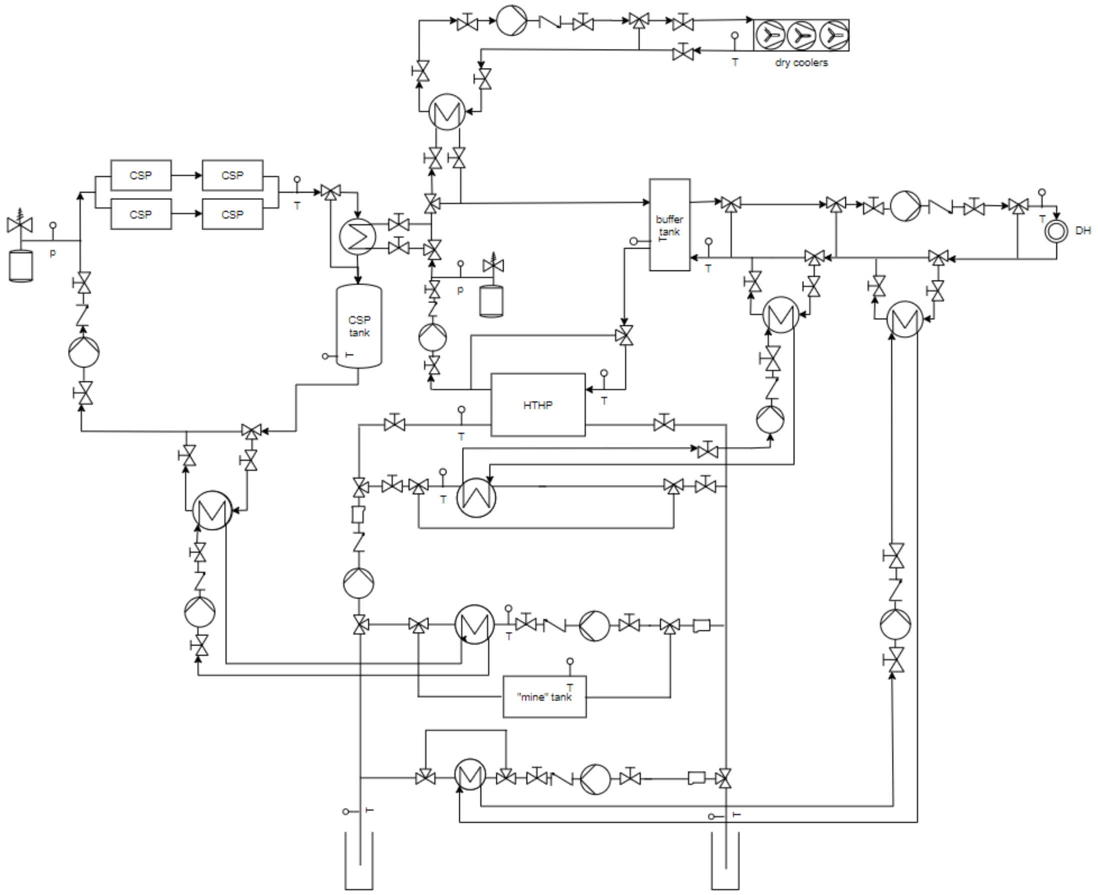

FIGURE 2. Piping and instrumentation (P&ID) current draft

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. Furthermore the district heating itself operates on different temperature levels.

Tested cascading systems

The three scales and cascading schemes presented have been tested during the development of the pilot site. These are in particular:

- **HTHP scale:** Heat pump stages tested
- **Local pilot plant scale (TRUDI):** CSP tested
- **Site scale** (Querenburg district): district heating and CHP plant

HTHP scale: heat pump stages tested

At the HTHP level, the cascading scheme was tested by and with Johnson Controls in their factory before shipping to Bochum. It was possible to assist at the tests online on the 17.08.22 and on the 08.09.22 of the R717 and R600 stage respectively. The ammonia stage was without container whereas the Butane was already enclosed.

In Fig.3 is shown the R717 unit, in Fig.4 the R600, during the tests.

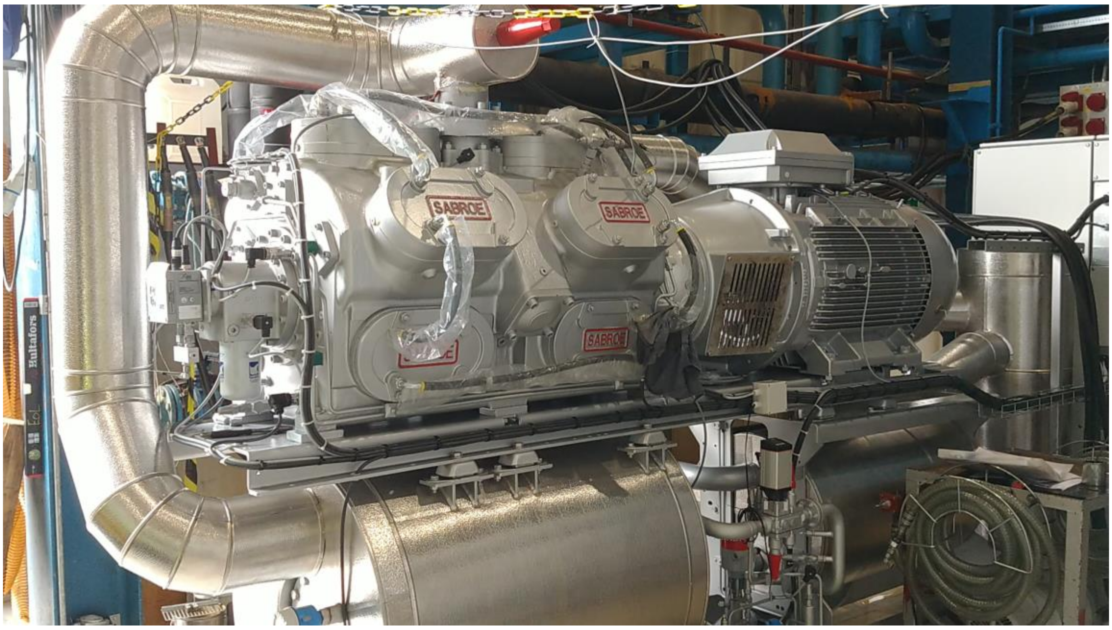

FIGURE 3. R717 unit during testing

FIGURE 4. R600 unit during testing

The measurements, performed by Johnson Controls follow the ISO R916, ISO 917 and EN 12900 normative standard. During the measurements, loggings are taken every 10 minutes, for a total of 4 measurements per unit. Then average values are displayed.

TABLE 1: R717 (ammonia) unit, test results

		Mean	Std. Deviation	COMP1
COMPRESSOR		Mean	Std. Deviation	COMP1
	Evaporation Pressure:	4,76 bar-a	0,02 bar-a	4,68
	Evaporation Pressure:	2,8 °C/R	0,1 °C	**2,3**
	Condensing Pressure:	21,30 bar-a	0,14 bar-a	21,04
	Condensing Pressure:	51,8 °C/R	0,3 °C	**51,3**
	Shaft Power Consump. II	100,3 kW	0,4 kW	**96,0**
	Suction Temperature:	NA °C	NA °C	**3,2**
	Discharge Temperature:	NA °C	NA °C	**135**
	Oil cooling load		kW	**9,6**
EVAPORATOR:	**Propylene Glucol**	Mean	Std. Deviation	COMP1
	Freezing Temperature:	-25 °C	0 °C	**-25**
	Flow:	57,8 m3/h	0,2 m3/h	**57,8**
	Inlet Temperature:	10,48 °C	0,1 °C	**10,0**
	Outlet Temperature:	4,96 °C	0,1 °C	**5,0**
	Capacity:	342 kW	8 kW	**309**
	Pressure loss:	0,16 bar	0,00 bar	**0,16**
CONDENSER:	**Water**	Mean	Std. Deviation	COMP1
	Flow:	71,0 m3/h	0,1 m3/h	**70,9**
	Inlet Temperature:	45.06 °C	0,3 °C	**45,0**
	Outlet Temperature:	50,27 °C	0,3 °C	**50,0**
	Capacity:	425 kW	4 kW	**412**
	Pressure loss:	0,39 bar	0,00 bar	**0,40**

TABLE 2. R600 (butane) unit, test results

		Mean	Std. Deviation	COMP1
COMPRESSOR		Mean	Std. Deviation	COMP1
	Evaporation Pressure:	3.54 bar-a	0.06 bar-a	3.69
	Evaporation Pressure:	37.5 °C/R	0.6 °C	**39.0**
	Condensing Pressure:	10.60 bar-a	0.01 bar-a	10.35
	Condensing Pressure:	NA °C/R	NA °C	**81.0**
	Shaft Power Consump. II	90.2 kW	0.5 kW	**91.7**
	Suction Temperature:	NA °C	NA °C	**63.0**
	Discharge Temperature:	NA °C	NA °C	**102**
	Oil cooling load		kW	**9.1**
EVAPORATOR:	**Propylene Glucol**	Mean	Std. Deviation	COMP1
	Freezing Temperature:	-25 °C	-25 °C	
	Flow:	76.7 m3/h	0.2 m3/h	**76.7**
	Inlet Temperature:	50.66 °C	0.0 °C	**50.0**
	Outlet Temperature:	45.07 °C	0.1 °C	**45.0**
	Capacity:	459 kW	8 kW	**427**
	Pressure loss:	0.33 bar	0.00 bar	**0.25**
CONDENSER:	**Water**	Mean	Std. Deviation	COMP1
	Flow:	22.8 m3/h	0.0 m3/h	**22.7**
	Inlet Temperature:	60.21 °C	0.1 °C	**60.0**
	Outlet Temperature:	80.00 °C	0.0 °C	**80.0**
	Capacity:	517 kW	2 kW	**527**
	Pressure loss:	0.04 bar	0.00 bar	**0.02**

Local pilot plant scale (TRUDI): CSP tested

The concentrated solar collectors CSP (Fig.5) were installed and tested. Heat injection and extraction tests were performed. In addition, models to represent the behaviour of the heat transfer tests were developed and validated.

FIGURE 5. CSP installed in Bochum.

The heat injection was performed with a temporary rented heater and the main installation is shown in Fig.6.

FIGURE 6. Installation for heat injection tests into the mine

Results of heat injection and extraction tests are reported in Fig.7. Heat injection was performed for about 1 week in December 2021 from the monitoring well. The temperature (red line) of the well increased to up about 50°C and after the test was concluded, the temperature went asymptotically towards the unheated temperature of 12°C. Heat extraction from the same well was performed in February 2022.

The water level was also measured and stayed approximately constant during the tests, as required.

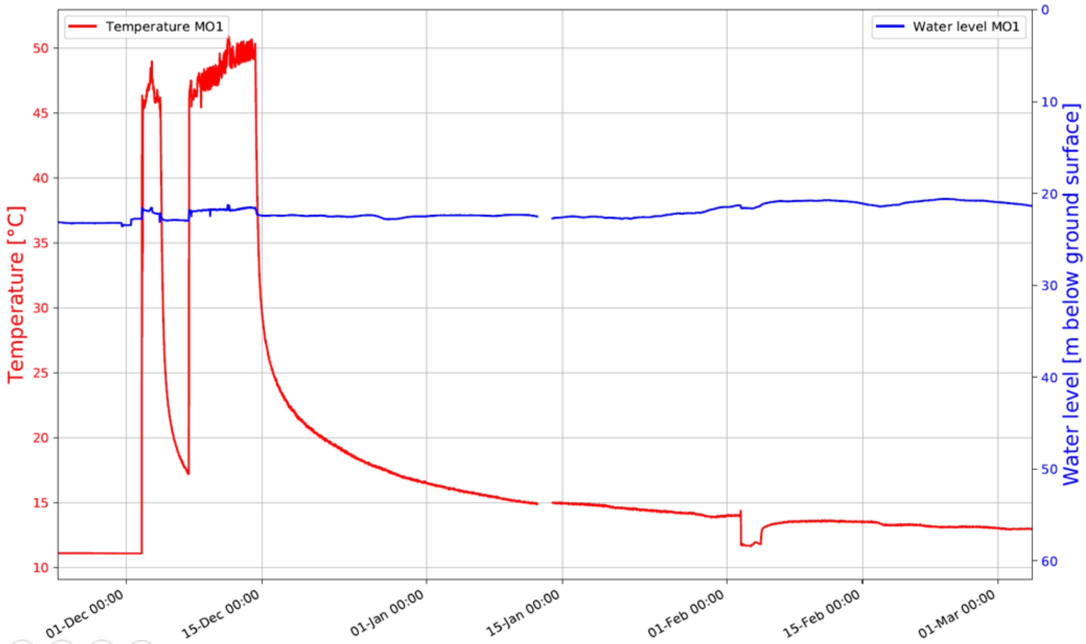

FIGURE 7. Heat injection and extraction test results

The behaviour was as expected and modelled.

Site scale (Querenburg district): district heating and CHP plant

District heating connection and functionality is tested every day. It was possible to have a look in more detail at the functionalities and operation of the district heating by visiting the plant owned by Unique.

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.

CHP and boilers were observed while running.

Conclusions

The three cascading schemes presented in WP T3 2.2., namely at the HTHP scale, at the local pilot plant scale (TRUDI), and at the site scale (Querenburg district), were tested and allow an optimal operation of the test site. The results of the tests are here reported.

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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