PUSH-IT

Piloting Underground Seasonal Heat Storage In geothermal reservoirs

D1.5 Commissioning report of installations MTES-Bochum - report of works and functioning of system and learnings from and integration and push-pull test

Funded by
the European Union

Grant agreement number	101096566		
Project title	Piloting Underground Storage of Heat In geoThermal reservoirs		
Project acronym	PUSH-IT		
Start date	01-01-2023	DURATION	48 months
End date	31-12-2026		
Work Package No. and Title	WP1 Demonstration and follower sites		
Deliverable number	D1.5		
Deliverable title	Commissioning report of installations MTES-Bochum - report of works and functioning of system and learnings from and integration and push-pull test		
Actual date of delivery	29-01-2026		
Nature	R	DISSEMINATION LEVEL	Sensitive
Deliverable Leader	Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.VRuhr-Universitaet Bochum		
Author	Stefan Klein		
Co-authors and contributors	Nadezda Meier, Franziska Krenzlin, Willem Hagemann, Florian Hahn, Idtz Wieling, Annick Loschetter, Andres Gonzalez Quiros		

Disclaimer

Funded by the European Union

Funded by the European Union under the Horizon Europe programme (grant no. 1011096566). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor CINEA can be held responsible for them.

Document history

Version	Description (Section, page number)	Author	Role (Organisation short name)
V0.1	First draft	Stefan Klein	F-IEG
V0.2	Second draft Processed of feedback received from reviewers / partners	Stefan Klein	F-IEG
V0.3	Draft final Processed of feedback received from reviewers / partners	Stefan Klein, Florian Hahn	F-IEG
V1.0	Final version	Stefan Klein	F-IEG

Quality control

Author	Organisation short name	Role	Date
Nadezda Meier	F-IEG	Work Package Leader	19-01-2026
Stefan Klein	F-IEG	Deliverable Leader	26-01-2026
Thomas Olver	GEL	Reviewer 1	12-12-2025
Amy Peach-Gibson	GEL	Reviewer 2	05-01-2026
Martin Bloemendal	TUD	Scientific Project Coordinator	23-01-2026
Danitsja van Heusden	TUD	Project Coordinator	29-01-2026

Table of Contents

List of tables

List of figures

List of Abbreviations

A2L	Group of refrigerant mixtures
ABI	Acoustic Borehole Imager
BGS	British Geological Survey
BLB	Bau- und Liegenschaftsbetrieb NRW (building and real estate management of NRW)
BMWF	Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research)
BRGM	BRGM – Bureau de Recherches Géologiques et Minières
CapEx	Capital Expenditures
CHP	Combined Heat and Power plant
delta h	delta h Ingenieurgesellschaft mbH
DHN	District Heating Network
DoA	Description of the Action
F-IEG	Fraunhofer Research Institution for Energy Infrastructures and Geotechnologies IEG
FUW	Fernwärme Universitätsstadt (District heating utility)
GRE	Glass-fibre-Reinforced-Epoxy
HCT	Huisman Composite Tubular
HT-MTES	High Temperature Mine Thermal Energy Storage
LCOH	Levelized Cost of Heat
M	Month
MTES	Mine Thermal Energy Storage
MU/BO	Make-Up / Break-Out
NRW	North-Rhine Westphalia (Most populous state in Germany)
OBI	Optical Borehole Imager
OpEx	Operating Expenditures
PCD	Polycrystalline Diamond
PV	Photovoltaics
RUB	Ruhr University Bochum
TC	Technical centre
TDA	Technische Universität Darmstadt
UTES	Underground Thermal Energy Storage
WGH	Wasserhaushaltsgesetz (German Water Act)
X-over	Crossover (connection tool in drilling industry of any kind)

Executive Summary

This document describes the work, which has been done within the first 36 months to prepare and install a novel High Temperature Mine Thermal Energy Storage (HT-MTES) system for the Ruhr-University in Bochum. It implies and highlights all the work steps including legal framework and permitting, feasibility results focussing on the utilization of surplus energy at the demo site, an individual stakeholder-management, communication of work package related tasks within the consortium, planning, drilling and completion of the wells as well as dissemination of the project scope and related topics belonging to the Mine Thermal Energy Storage (MTES) technology given by talks and poster presentations at different events.

The status at M36, is that a production, injection and further monitoring well have been installed.

1. Introduction

PUSH-IT will showcase full-scale application of high temperature heat storage (up to 90°C) in geothermal reservoirs using 3 different technologies, in aquifers, boreholes and mines, at 6 different sites. The 3 technologies addressed in PUSH-IT are relevant for different geological conditions, which are widely available in Europe. The PUSH-IT project will develop, deploy and test our technologies for a variety of configurations of heat sources, heat storage technologies, geological conditions, distribution systems, stakeholder populations and market and legal conditions. Hence, PUSH-IT provides a unique scope on demonstration, integration and advances for seasonal heat storage. These results will enhance the utilisation of sustainable energy and create a balanced system for sharing benefits and burdens tied to sustainable heat generation, storage and distribution activities.

PUSH-IT will reduce environmental impact, levelized cost of energy and risks, whilst improving performance and robustness via development and demonstration of several enabling technologies, i.e., newly developed monitoring and water quality control, novel drilling and completion and novel control systems. Societal engagement is a key element and achieved via citizen engagement, analysing motivations and perceptions of heat storage, and investigating governance policies and business models that engage citizens in decision making regarding urban heating systems including storage. The PUSH-IT consortium combines heat suppliers, well drillers, public planning offices and academic partners. Through our transdisciplinary collaboration we will realise operational projects and use these to generate generic solutions and practices relevant across Europe. All activities will be monitored and reported, yielding a valuable comprehensive dataset on the technical and social real-world performance.

1.1. Goal of this Report

One of the 6 sites where the PUSH-IT project develops and demonstrates heat storage in geothermal reservoirs is Bochum, North-Rhine Westphalia (NRW), Germany. Here, mines formerly used for hard coal production, which are currently abandoned, are being transformed into a Mine Thermal Energy Storage (MTES).

The goal of this report is to describe the commissioning and system installation and coordination of the proposed PUSH-IT activities at the demo site in Bochum, as well as coordination of activities outside the project but relevant for PUSH-IT.

The overall goal of the PUSH-IT consortium is to realize the successful implementation and operation of the pilot sites. This implies preparation, installation and operation of infrastructure, and engagement with local stakeholders, analysing and evaluating economical value and relevance, assessing geological aspects of storage sites, integration and control.

2. Site Description

The demonstration site is located at the technical centre (TC) of the Ruhr University Bochum. The targeted mine galleries are directly beneath the premises at a depth of 120 m below ground. The project aims to integrate the MTES technology to support the university's heating and cooling network.

The complete infrastructure is owned and managed by the building and real estate management of North-Rhine Westphalia.

The campus heating grid is operated by the southern Bochum energy provider *Unique Wärme GmbH* (a joint venture between the university and the Stadtwerke Bochum Holding) and is fed with dissipated heat by a combined heat and power plant (CHP) supported by three gas fired boilers.

Furthermore, the university operates its own cooling grid supplied by turbo chillers.

The university's data centre was also built at the technical centre in 2021 and is supplied with cold air for the server racks, generated by a turbo chiller as well as additional free coolers (700 kW in peak).

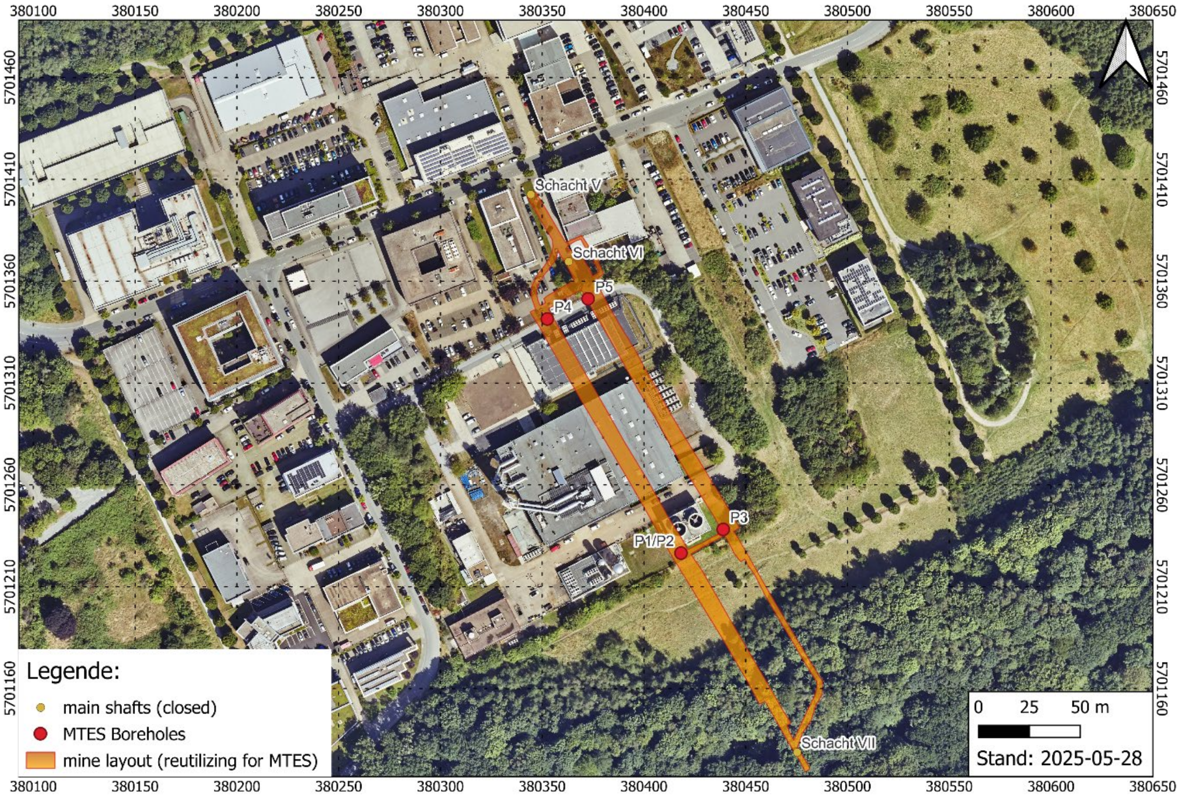


Figure 1: Aerial view on the Bochum demo site showing the targeted former galleries of the abandoned colliery Bochum-Mansfeld in a depth of 120 m below the technical centre. The borehole P1 is a 152 m deep monitoring well directly located next to the MTES wells P2 and P3 behind the cooling towers, the boreholes P4 and P5 will be drilled in front of the data centre at the northern boundary of the RUB premises. This setup was chosen to maximize the potential of the thermal utilization of the former galleries with approximately 150 N-S and 20 m W-E, respectively. All energy sources for the DHN (CHP unit, the gas boiler as well as the turbo chillers) are in the factory in the middle between the MTES wells.

2.1. Objectives

The purpose of the Bochum demo site is to decrease the overall energy consumption of the existing heating and cooling grid. The PUSH-IT project aims to accomplish this purpose by:

1. Reutilization and integration of mine water from the abandoned Mansfeld-Colliery as a local and renewable (low-enthalpy) energy source and storage,
2. Storing (surplus) heat occurring from refrigeration into the subsurface and
3. Implementation of a connection and control system for suitable heat pump unit(s), in order to boost the temperature to more than 90 °C in the future to meet the desired thermal energy demand.

2.2. Location

As already described in D1.1, the demo site is located at the university's technical centre (TC), and is to be integrated into the existing District Heating Network (DHN), which supplies not only heat to the entire Ruhr University Bochum (RUB) campus with around 5,700 employees and 43,000 students but also for a large grid of the energy provider *Fernwärme Universitätsstadt* (FUW) for around 4,800 rental apartments, 760 domiciles and 115 other customers nearby (Figure 2).

The energy producer is the *Unique Wärme GmbH*, a Joint Venture between the University and Stadtwerke Bochum Holding, founded in 2018.

To supplement the whole location with energy, a total of 100 MW for heating and 10 MW for cooling has been installed at the technical centre.

Figure 2: Aerial view on the entire RUB campus with circa 30 different buildings of age, size and energy demand as well as adjacent rental apartments, domiciles and further customers on the left part of the aerial photograph.

An overview of the district heating tracks is illustrated in Figure 3. The CHP is the main power plant for both electricity and heat supplementing the RUB power grid as well as the external district heating grid owned by FUW. Besides, the RUB utilises pressured air, Photovoltaics (PV) and district cooling for its own power grid.

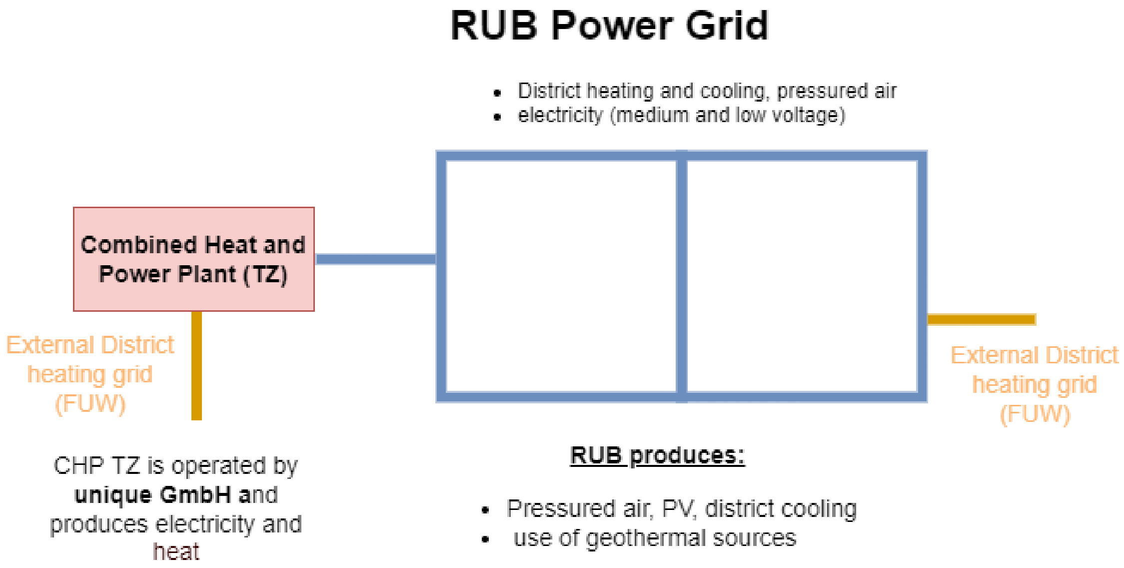


Figure 3: Overview of the district heating network tracks at the Bochum campus feed by energy of a combined heat and power plant connected to the RUB power grid (blue) and the external FUW district heating grid (orange)

2.3. Stakeholders

In the context of PUSH-IT, the main stakeholder is the RUB, which operates the heating and cooling grid at the campus. Discussions are also planned with the Stadtwerke Bochum Holding, which have a 50 % association with the *Unique Wärme GmbH*, which is responsible for the current heat production of the heating grid.

During a stakeholder workshop, a matrix was created to better manage the project by collecting and categorizing each individual stakeholder. The matrix demonstrates the individual influence of the stakeholder in contrast to the general interest of the project.

In addition, the individual conflict potential has been evaluated for each stakeholder and corresponding strategies have been chosen. The strategies either imply a passive (informative strategy) role, active engagement with the stakeholder (participatory), or direct involvement (discursive strategy) as required actions for occurring conflicts (Table 1).

Figure 4 illustrates the results of stakeholders analysis in a spatial matrix where the influence is plotted over the individual interest of the project.

When completing the “influence in the project” and “interest of the project” columns, three different evaluation attributes (low, medium, high) were used, and therefore the individual cells of Figure 4 have been accordingly coloured in green, yellow or red, respectively (Figure 4).

Table 1: Identification of individual stakeholder conflict potential including management and prevention strategies

No.	Stakeholder	Interest of Project Development	Influence of Project Development	Conflict potential	Strategy
1	Grant Funder (EU)	high	low	high	informative
2	Grid operator	medium	medium	high	discursive
3	Consortium	high	low	medium-high	informative
4	Local residents	low	low	low-medium	informative
5	Environmental Agencies	low	medium	medium-high	informative
6	Mine Owner	low	high	high	participatory
7	Landowner	low	high	medium-high	participatory
8	Technical Staff at Demo Site	medium	medium	low	discursive
9	Media	medium	low	low	informative
10	Water Authority	high	high	medium	participatory
11	Local Politics	high	low	low	discursive
12	Subcontractors	medium	high	medium-high	discursive
13	Ruhr-University	high	high	high	discursive

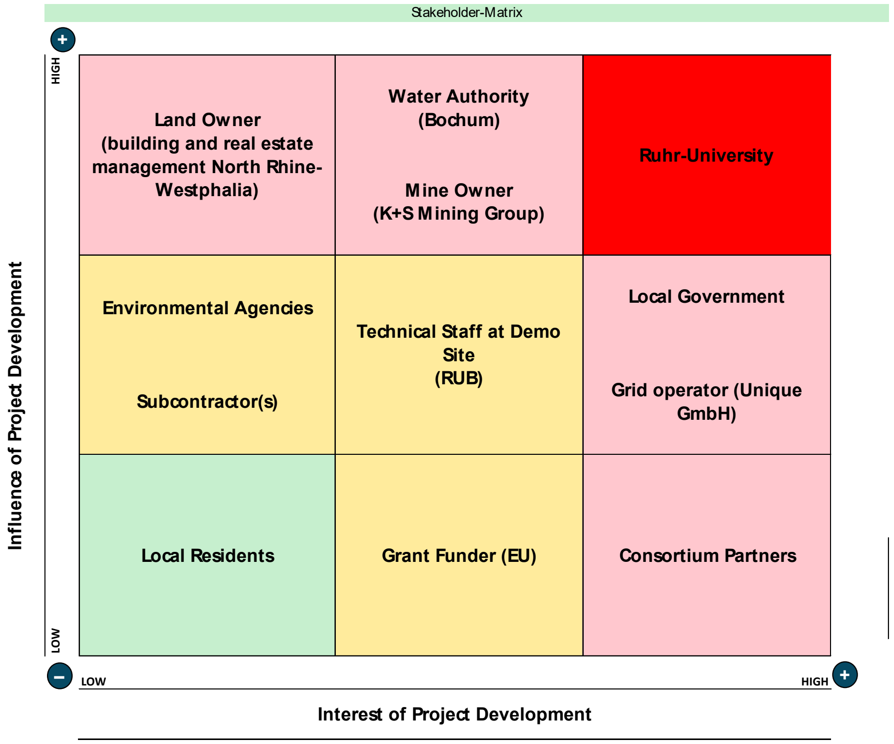


Figure 4: Stakeholder Matrix for the PUSH-IT Bochum Demo Site (MTES) ranging from stakeholders with generally a low interest and influence (i.e. residents coloured in green) to stakeholders with a high interest and also a high influence (i.e. the Ruhr University Bochum as the main beneficiary)

2.4. Current Status

In the first 12 months of the PUSH-IT project (M1-M12), unexpected legal issues arose which caused a deviation from the original work plan for the implementation of the MTES proposed for M18, specifically the requirement to obtain the land and mine owner's final permission in written form (obtained from landowner first in M13, from mine owner in M17). This further delayed the necessary agreement with the RUB as the main beneficiary on this site for the construction of a drilling site at the TC.

Table 2: Preparation for Task 1.3. Bochum comparing the proposed due months with the actual dues.

No.	Task	Proposed Due according to original GA	Actual Due	Deviation [M]
1.	Legal Framework	M1-6		
1.1	Obtain complete mine layout		M8	2
1.2	Digitization of mine layout		M9	3
1.3	Receiving legal permit from landowner		M14	7
1.4	Obtaining permit for test operation from water authority		M15	9
1.5	Signing contract (release of liability) for drilling and test operation with mine owner		M17	11
1.6	Agreement for MTES installation at TC with university		M20	14

Once all the necessary legal and liability agreements had been signed, work could begin on site. In order to minimise impact of deviation, the drilling site was prepared in parallel with the signing of the final agreement between RUB and F-IEG (Figure 5). The drilling of a monitoring well (P1) and a production well (P2) was successfully completed during Q4, 2024. This was accompanied with geophysical logging, imaging runs and HCT installation tests. The first monitoring well was completed and prepared for monitoring measurements in M22. Within the production well, the Huisman Glass-Fibre-Reinforced Epoxy (GRE) casing was successfully installed in M24, and the well was completed just before Christmas.

Figure 5: Construction of the demo site in Bochum

The completion of the first two boreholes allowed us to commence a baseline monitoring programme, as well as the active involvement of other project partners on site (e.g. microbiological sampling with Bureau de Recherches Géologiques et Minières (BRGM).

After the return of the drilling rig in M35 from the necessary overhauling and upgrading works done by the manufacturer, the well P3 was successfully drilled and investigated via geophysical surveys and camera runs.

As a next step, hydraulic tests are planned to elaborate the performance of the installed system.

3. Drilling and Completion

The drilling and completion works were done with the F-IEG institute's rig *Hütte HBR 207 GT*. In order to accommodate 9 5/8" casings for the planned wells, large conductor pipes with accessories had to be purchased for the F-IEG drilling rig within the PUSH-IT project.

The new conductor pipes have a diameter of 14", so that drilling with a larger diameter is now possible (12 ¾"). This enables the installation of 9 5/8" casings and henceforward up to 8" electrical submersible pumps for high productions rates.

All boreholes are drilled with a diameter of 323,9 mm to a depth of approximately 120 m below ground level.

The rig was moved to the points indicated on the site map in Figure 1 before drilling mud, separator and container for the borehole cuttings were connected via high-pressure hoses (Figure 6). In order to secure the first meters of loose rock against unravelling, conductor pipes were temporarily installed and removed again before cementation.

As shown in Figure 7, a 12 ¾ "-Polycrystalline Diamond (PCD) drill bit was used for direct flush drilling.

Figure 6: Drilling setup at the demo site showing the drilling fluid circulating system

Figure 7: F-IEG drilling rig Hütte HBR 207 GT showing a 12 ¾ "-PCD bit attached to heavy drill collars in order to realize a preferably vertical pathway without using any additional (cost-intensive) Rotary Steerable System tools

3.1. Preparation / Design of Completion tools

Within the scope of Work Package 3 Task 3.1, a collaboration with Huisman Equipment B.V. has been initiated to prepare guidelines and procedures for an enhanced well completion with Huisman-Composite-Tubular (HCT) casings made of glass-fibre-reinforced-epoxy (GRE) for two of the boreholes at the demo site in Bochum (Figure 8).

Since there are no standard technology, additional auxiliary tools and items were designed and manufactured. Examples of these required items for the well installations are:

- An individual Crossover to the Top Drive of the deployed rig (Figure 9a)
- An individual X-over to a (wire-wrapped) screen section (Figure 9b)
- Additional Interface Make-Up / Break-Out (MU/BO) clamp to collar (Figure 9c)
- Special C-Plate to prevent the string from falling into the well when other components fail (Figure 9d)
- HCT sleeve for smoother pipe handling with excavator grippers (Figure 9e)

All items have been successfully tested during running and installation tests in October 2024.

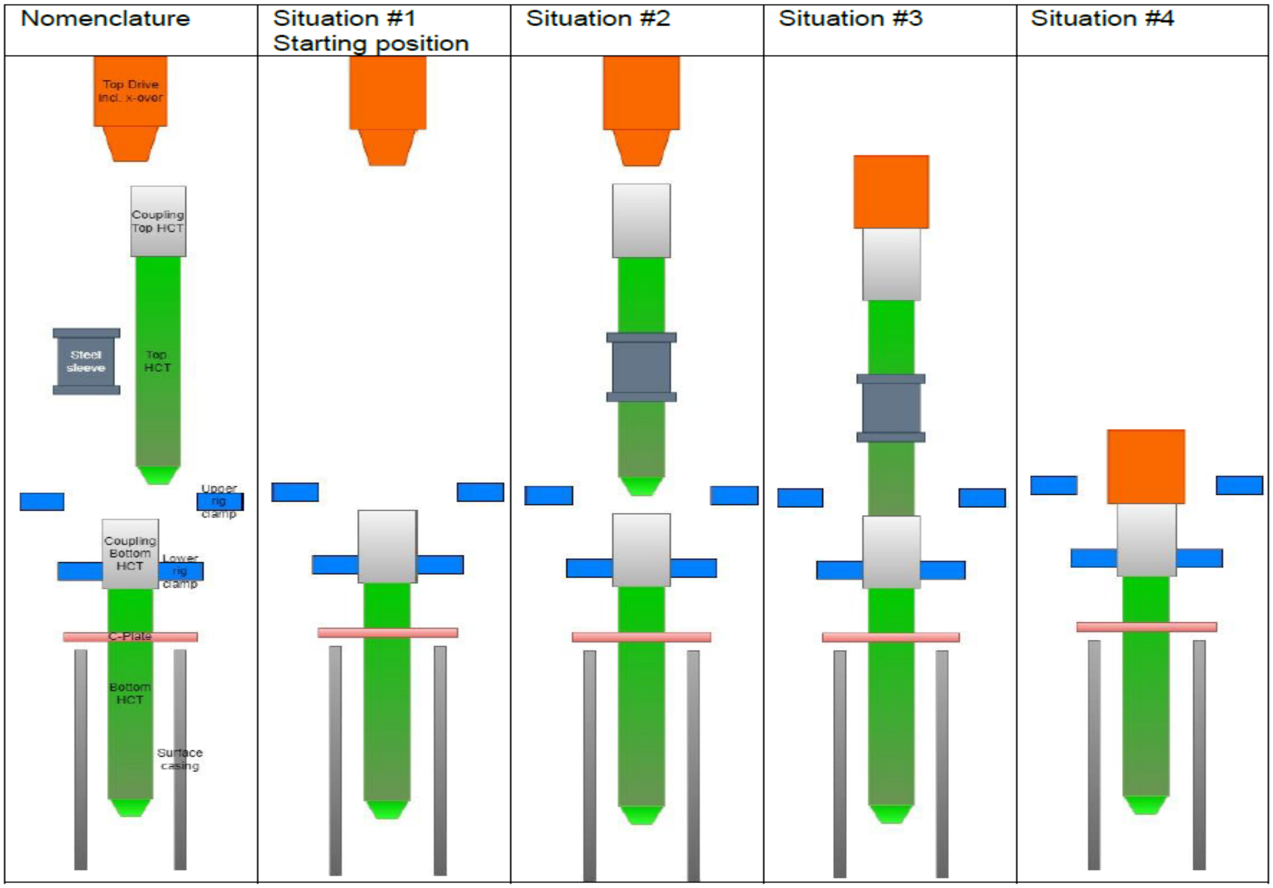


Figure 8: HCT Running and installation procedure for the deployed rig Hütte HBR 207 GT (© Huisman Equipment B.V.)

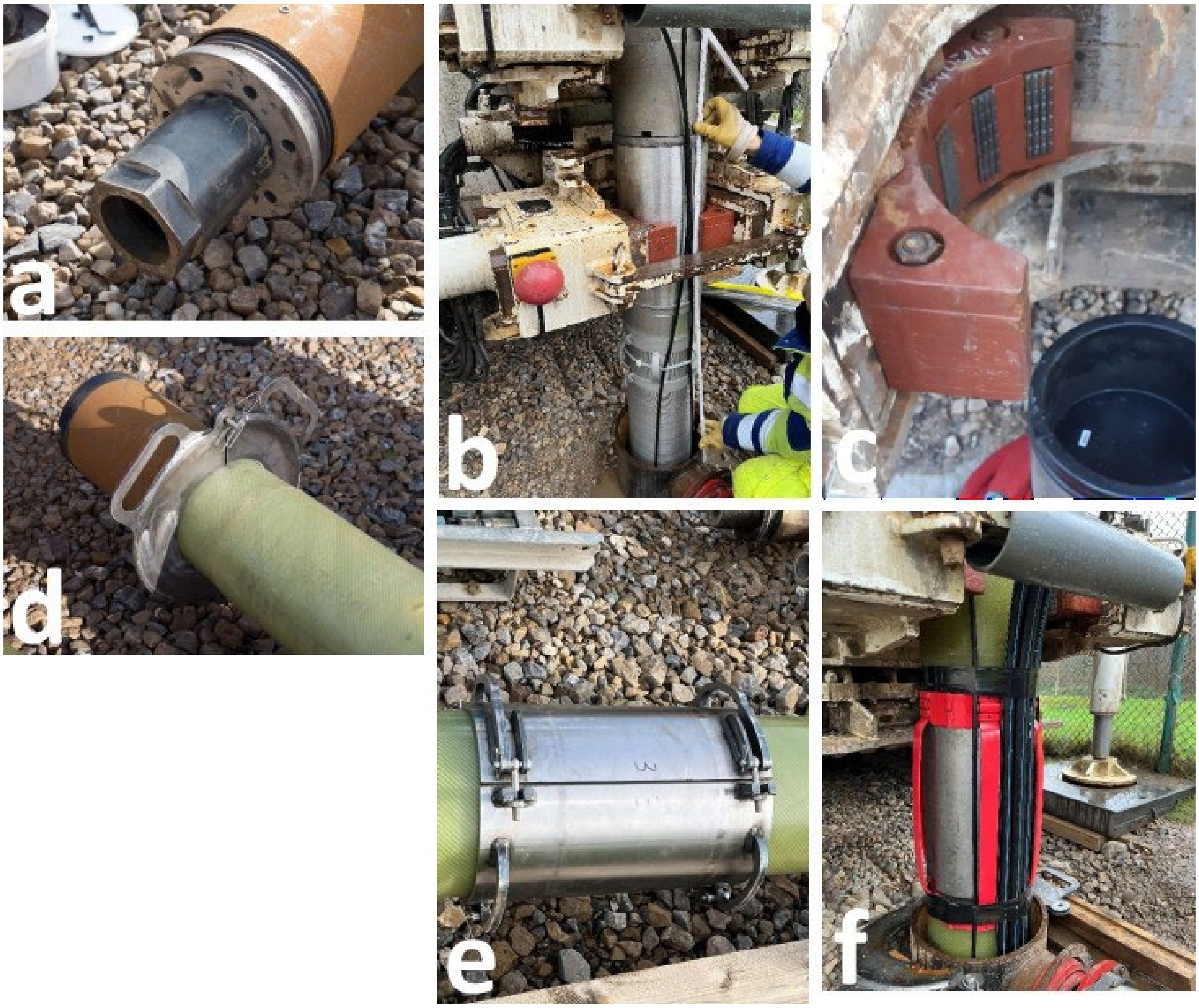


Figure 9: HCT Items required and tested for the MTES boreholes at the demo site

3.2. Well Completion

As part of the PUSH-IT WP3.1, the boreholes P2 and P3 are equipped with HCT-Casings above the former mine workings in the overburden intact rock formation.

The annulus was cemented in multiple stages from bottom to top using injection hoses. In order to create a hydraulic connection to the former galleries and to ensure a large inflow volume, each borehole was equipped with a wire-wrapped screen section below the HCT casings (DN225).

3.3. Rock cutting Analysis

Borehole cuttings were sampled every meter during the drilling operation and analysed (Figure 10). The cuttings from the Carboniferous overburden rocks (see D1.1 workplan) appeared to be varying in size and clay content. It was observed that cuttings from softer clay formations are darker and smaller than cuttings from interbedded harder sandstone units. During the borehole drillings, three thin coal seams were penetrated. These were later recognized in geophysical logs as well as DTS measurements of the overburden rock.

Figure 10: Rock Cutting Analysis. Here, dark and soft claystone cuttings can be observed

3.4. LOGs

Geophysical logs (i.e. Borehole Trajectory, Gamma Ray, acoustic and optical borehole televiewer) were conducted after the drilling. Gamma Ray logs assisted to depict the clay content for 1D geological profiles. The gamma ray tool was stacked together with a deviation measuring probe to reconstruct the borehole path. More information and results can be gained in Deliverable 3.6.

The (optical/acoustic) borehole televiewer results were essential before well installation took place in order to both grout and seal the borehole annulus above the targeted MTES drifts with a packer in a suitable formation true to the borehole size.

Figure 11 shows the borehole path and focuses on the penetration of sandstone units interbedded by three thin coal seams in ca. 30, 50 and 60 m depth.

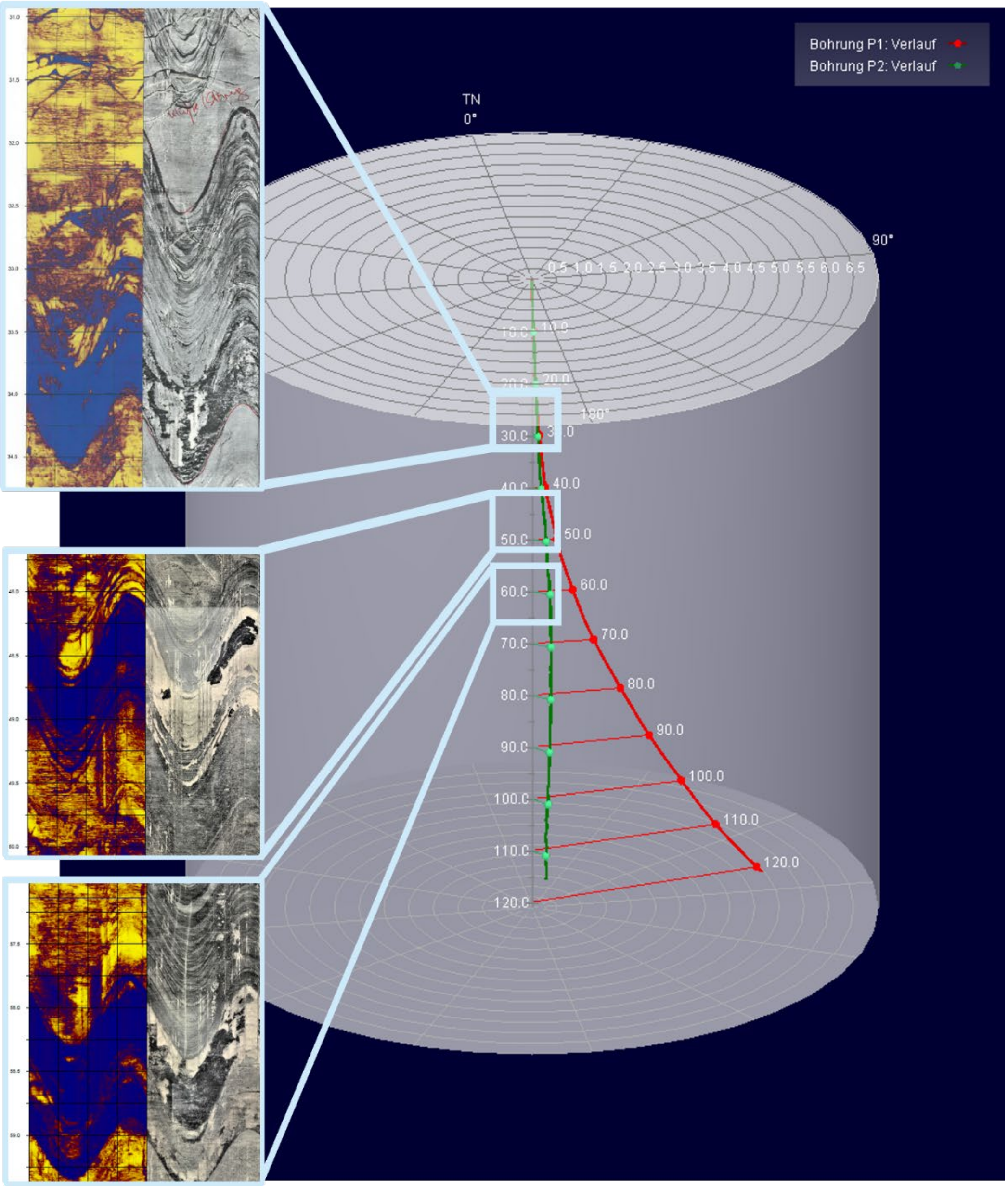


Figure 11: Example of borehole logging results illustrating borehole azimuth and tilt as well as ABI and OBI measurements, respectively for the first two boreholes P1 and P2.

4. Performance Assessment and Optimisation

Within WP3.4, a co-simulation of the overall setup was developed for the demo site to optimize the heating network's efficiency by modelling various sub-surface loading and unloading scenarios.

First conceptional results for the subsurface modelling are shown in Figure 12. The subsurface modelling is part of another project, individually funded by the Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research) (BMWF) and carried out by the company *delta h Ingenieurgesellschaft mbH (delta h)* using its own software SPRING®.

The planned procedure entails constructing first a subsurface model using SPRING®, while Technische Universität Darmstadt (TDA) collaborates with delta h to integrate the subsurface model results with surface grid models coupled via a common mock-up unit using the software SimulationX / Dymola with help of a MSc thesis (Spengler 2025).

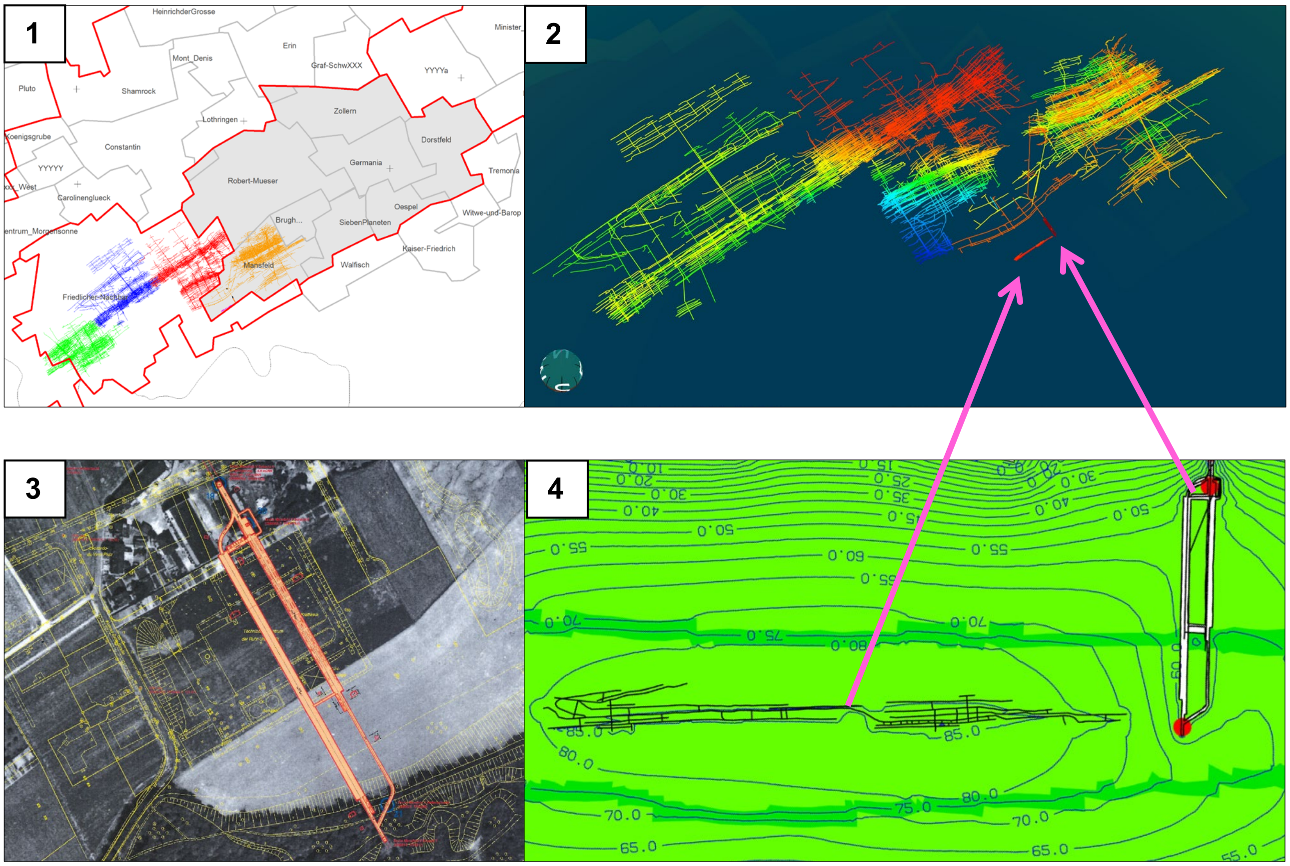


Figure 12: Stepwise model development at the MTES Demo Site from a regional to a local scale. 1. Implementing boundary conditions on a regional scale according to the individual mine water provinces and heads in NRW. 2. 3D visualization of all neighboring mining layouts. 3. Local model of the targeted two drifts for the intended MTES utilization beneath the TC. 4. Plotting preliminary results (hydraulic head contours) influenced by the adjacent colliery beneath F-IEG based on first numerical model runs (© deltah / F-IEG)

The cooling network on the RUB campus has a total length of approximately 8 km and is operated with planned temperatures of 8/14 °C (supply/return) in the central cooling network and 10/16 °C (supply/return) in the connected buildings.

In actual operation, however, there are smaller temperature differences of only 2.5 °C in the cooling network due to an inefficient cold transfer to older un-refurbished buildings. In those buildings the transfer from the cooling network to the consumers takes place without a hydraulic separation via 3-way valves, which means that the supply and return flows are mixed when there is little or no cooling demand.

Theoretically, the cooling network has a capacity for supplementing 32 MW, of which only around 25 % is utilized in peak.

Due to the capacity limit of the installed turbo chillers, the cold production in the technical centre is limited to 3 x 3,6 MW. For this reason, any additional cooling that is required has to be generated locally at the individual RUB buildings. The maximum cooling capacity provided for the individual buildings is guaranteed by a maximum flow limiter. The temperature spread on the primary production side at the transfer station is 7°C to 9°C / 15°C with a sliding, load-dependent flow temperature.

The complete refrigeration infrastructure belongs to the building and real estate management of North Rhine-Westphalia (Bau- und Liegenschaftsbetrieb NRW (building and real estate management of NRW): BLB) and is rented and operated by RUB. The cooling demand in the network is mainly used for direct or indirect appliance cooling, air conditioning only accounts for a minimal part of the cooling demand.

Newer buildings are equipped with its own air-cooled chillers to ensure dehumidification requirements (due to lower temperature requirements of 6/12 °C than the central cooling grid is able to supply). Hence, more than 50 decentralised chillers are currently in operation on the RUB campus. In addition, two cooling systems with natural refrigerants (CO2/Group of refrigerant mixtures: A2L) are currently being planned.

4.1. Connection Plan Concepts

The greatest opportunity for increases in efficiency within the campus cooling supply is seen in the consumers and the transfer stations; in particular, the hydraulic separation of the existing buildings from the network offers considerable potential for optimisation. Efficiency efforts in system operation have also been underway for three years. Thus far, particular focus has been on optimisation of pump operation in the buildings. While complying with the boundary conditions with regard to hazards and personnel utilization, the air exchange requirements have been reduced from eight-fold to two-fold in many places, significantly reducing electricity consumption in the individual buildings.

At the technical centre, three turbo chillers of 3.6 MW each (refrigerant: R134a) are operated in parallel at partial load at approx. 30 to 35% capacity. This mode of operation is necessary because the heat exchangers in the chillers are limited to 600 m³/h and the grid is connected via an open hydraulic separator, which means that the total volume flow of the chillers must be equal to the grid volume flow varying between 800 to 1200 m³/h.

The turbo chillers are cooled via two wet (sprinkling) towers, each with a maximum output of approx. 11 MW.

The sprinkling water also serves as process water, but there is still a considerable demand for water throughout the year due to evaporation and maintenance (e.g. cleaning blow-downs). Around 100 m³ of water at temperatures of 16°C to 17°C (26°C to 28°C in summer) is stored in the towers.

The cooling water circuit is operated with two redundant pumps at approx. 1,800 m³/h at temperatures of 16/22 °C and 22/28 °C in summer, resulting in an average electricity requirement of 2 MWh/day.

From the current perspective, there are two main scenarios with various sub-options for the integration of MTES into the cooling supply and the associated waste heat utilisation. A combination of the individual options is also conceivable in some cases. The basic advantage of mine water integration is the combined storage of waste heat for later use as a low-temperature heat source. At the same time, heat pollution to the urban environment can be limited and the electricity requirement for the cooling water circuit can be reduced. Furthermore, a significant amount of water (~43.000 m³/year) could be saved.

Figure 13 (concept 1) shows a possible integration of the MTES into the cooling system by connecting it to the air-cooled turbo chiller in the RUB data centre. Due to a higher cooling temperature level in the data centre, a direct integration of the MTES could be implemented. The costs of integration are estimated to be comparatively low because of the proximity of the data centre to the Mansfeld colliery. An open question is to what extent the cooling capacity requirement and the security of supply requirements can be ensured by the MTES connection.

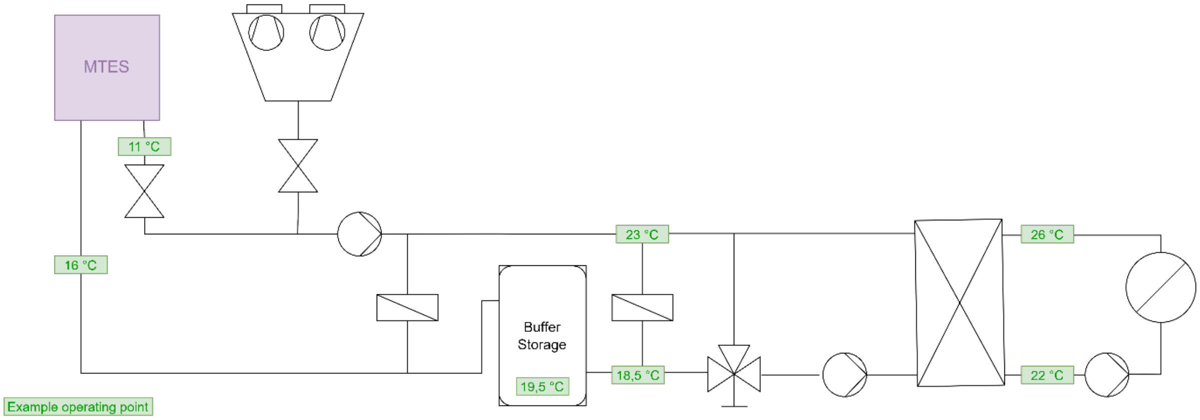


Figure 13: Concept 1 - Connection of MTES to data center

Figure 14 shows a second concept of possible integration of the MTES into the central cooling system of the technical centre with either partial or full replacement of the wet sprinkling towers.

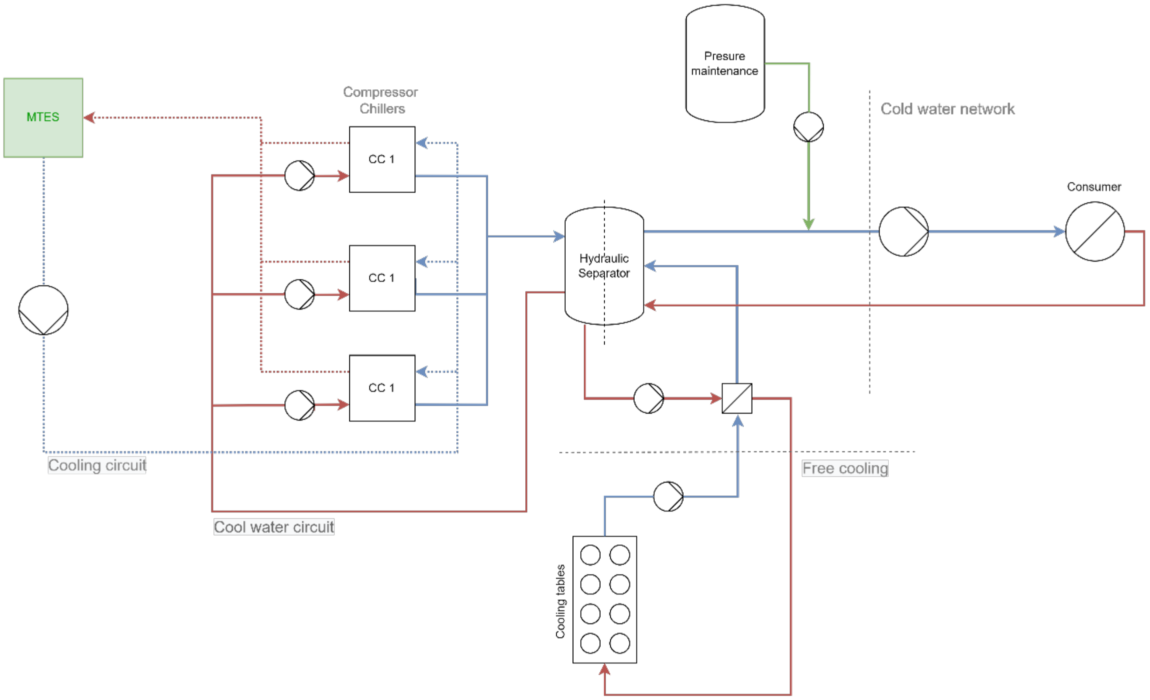


Figure 14: Concept 2 - Connection of MTES to the existing central refrigeration system (cooling circuit)

With a view to a future installation and integration of heat pump unit(s) outside of PUSH-IT, both surplus heat and mine water could serve as possible sources, if the current central cooling grid continues to exist (Figure 15).

Initial comparisons of the quantities of heat and cold produced at the demo site show that a combined use of the existing waste heat from the cooling system (> 2 MW as minimum base load throughout the year) would also be conceivable for direct integration into the heat supply. Due to a continuous heat production of the installed CHP units (~ 7.5 MW) throughout the year, there is a significant heat surplus from the central cooling by the turbo chillers during the summer period, which could be stored seasonally in the mine buildings (Figure 16).

Once the technical framework conditions have been clarified, the respective implementation option must be selected from the point of view of maximising the usable storage of waste heat or cooling by the mine water while maintaining the economic boundary conditions.

Different scenarios were investigated economically and technically within the co-Simulation feasibility study**.**

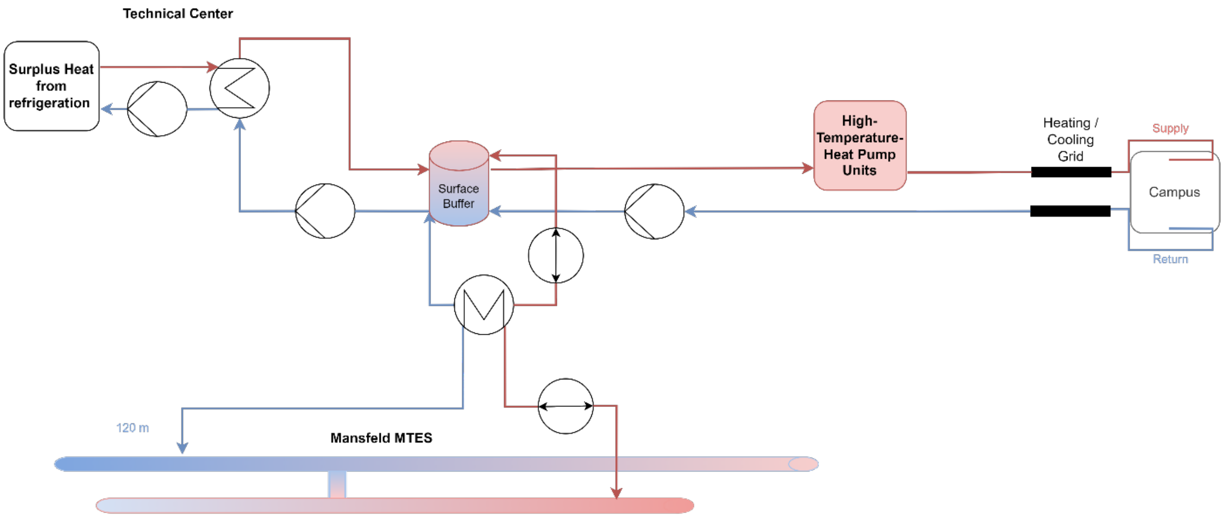


Figure 15: Systemic optimization of the heating and cooling network at RUB by integration of surplus heat occurring from refrigeration into the heating grid. To balance seasonal mismatches, surplus heat could be stored into the Mansfeld MTES.

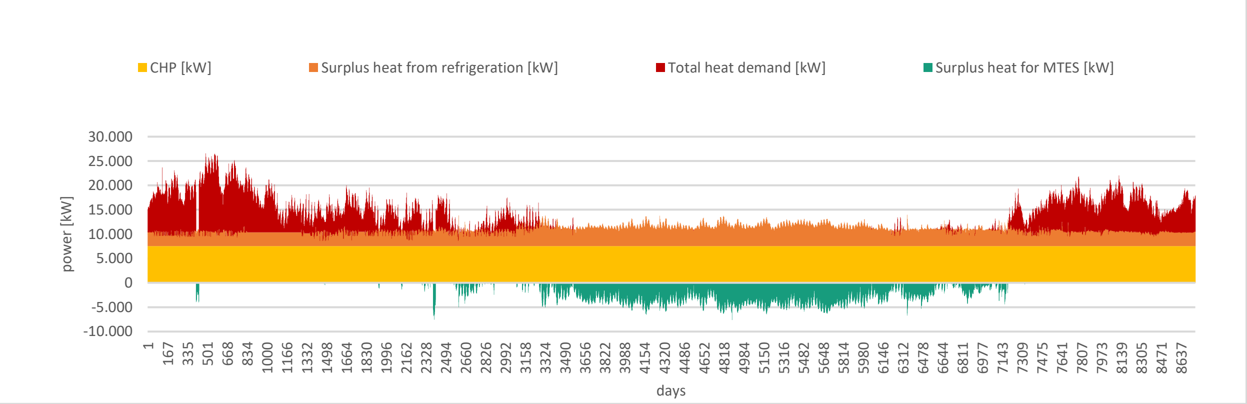


Figure 16: Energy ratio comparison between heat and cold production throughout the year. This graph should emphasize on the potential for MTES as an energy balancing unit for surplus heat from refrigeration during the summer period.

4.2. Co-Simulation

The fundamental idea behind an optimised system is to use the waste heat, which is currently being discarded into the atmosphere by the cooling tower, in the heating cycle. This means that the cooling tower will discard less heat, and the gas boiler will be used less frequently.

To realise the idea for the optimised system, there are two main steps that need to be implemented:

1. A heat pump will be installed between the turbo chillers and the cooling tower. This heat pump uses the output of the turbo chillers (on the condenser side) as its own input (on the evaporator side) and upgrades the heat for use in the heating cycle. As the cooling demand is relatively continuous throughout the year, the heat pump will provide a consistent base load for the heating cycle alongside the CHP plant.

2. If there is no current heating demand or an excess of waste heat, the MTES will store this extra thermal energy. This can be used later when needed. To unload the MTES, another heat pump is implemented in the new system. This means that the optimised system comprises one heat pump for charging the MTES, one for discharging the MTES, and the MTES itself. Three-way valves are also used to control the flow. The optimised system is visualised in Figure 17.

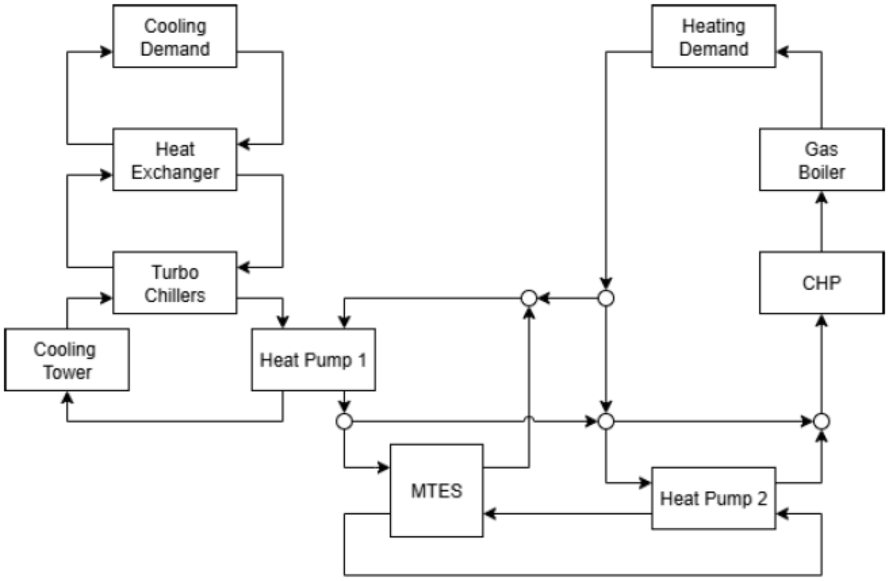


Figure 17: Optimised configuration of the heating and cooling system of the Ruhr-University Bochum.

To set up such a system, two models must be considered: one for the MTES and one for the RUB's heating and cooling system. Figure 18 shows a Modelica model of the heating and cooling system. This model also includes an MTES block, which will be necessary for connecting the MTES model.

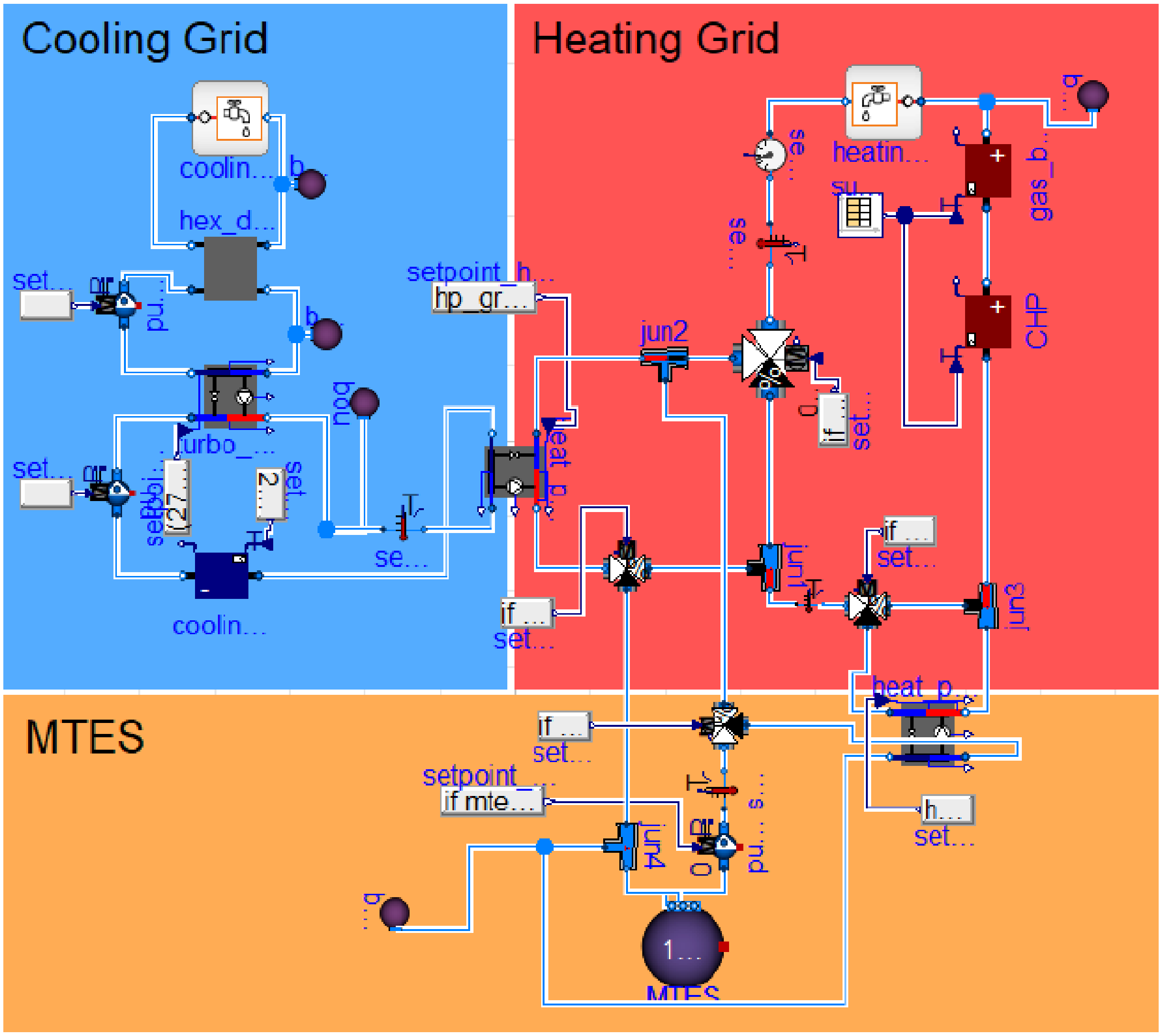


Figure 18: Modelica model of the optimised system calculating mass flow and energy balance throughout the year with respect to the energy components (e.g. CHP, cooling tower, common heat exchanger, connection to the MTES system via three-way-valves etc.).

4.3. Control Strategy

The control strategy is based on different scenarios. These scenarios are determined by if-statements with certain boundary conditions. The outcome of these if-statements determines how the three-way valves (represented by small circles in the schematic diagrams) are opened, as well as the setpoints for the different components. These different scenarios are explained in detail below. It is important to note that the control strategy only affects the way the heating side is being run.

The base case scenario visualised in Figure 19 is the current operation of the heating system (heating demand is covered by the CHP in combination with a gas boiler).

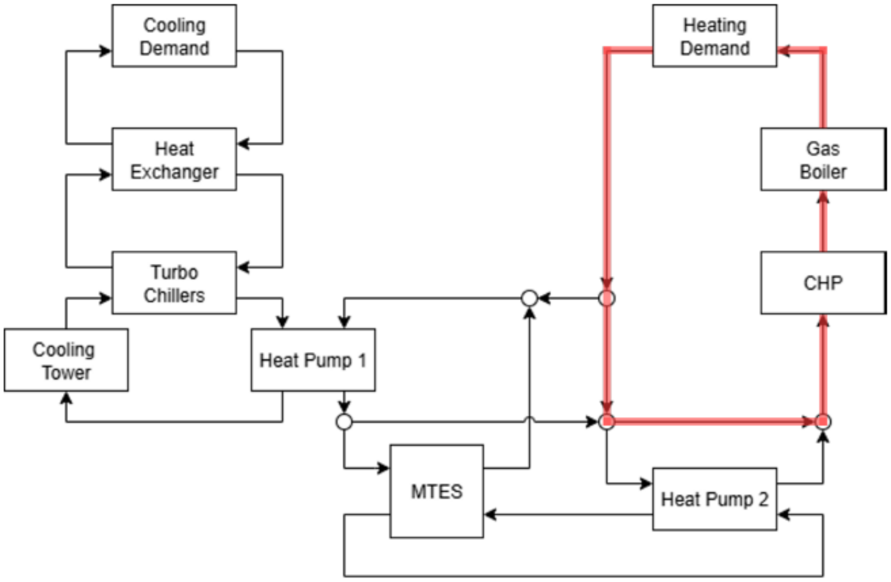


Figure 19: The control strategy for scenario 1.

The MTES charging scenario, visualised in Figure 20, is similar to the base case scenario, in which the entire heating demand is covered by the CHP. In this case, however, heat pump 1 can deliver waste heat. This means that there is sufficient thermal energy available on the evaporator side of the heat pump to prevent the evaporator outlet temperature from dropping below zero. Additionally, the temperature difference between the evaporator and the condenser of the heat pump is sufficient. As previously mentioned, the heating demand is already covered by the CHP in this scenario. This means that the waste heat from the cooling cycle cannot be supplied into the heating cycle and is instead used to charge the MTES. This holds true, if the MTES temperature remains below the maximum set temperature.

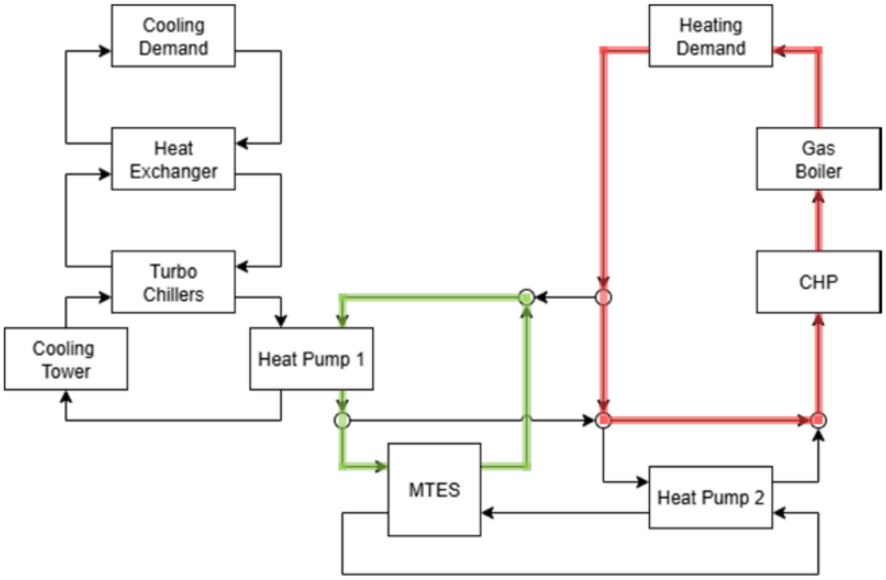


Figure 20: The control strategy for scenario 2.

The third scenario, visualised in Figure 21, describes the situation in which heat pump 1, combined with the CHP, provides the heating demand. For the flow to be directed to heat pump 1 after the heating demand block, the if-statement containing the equation $Q_{Demand,Heating} - Q_{CHP} > 0$ is true. In this case, some heating demand remains, which can be met by using the waste heat. Note that the remaining demand can be entirely covered by heat pump 1, which is why the MTES is not discharged. Additionally, heat pump 1 can only engage in one mode of operation. This means that it cannot provide waste heat to the heating cycle and charge the MTES simultaneously.

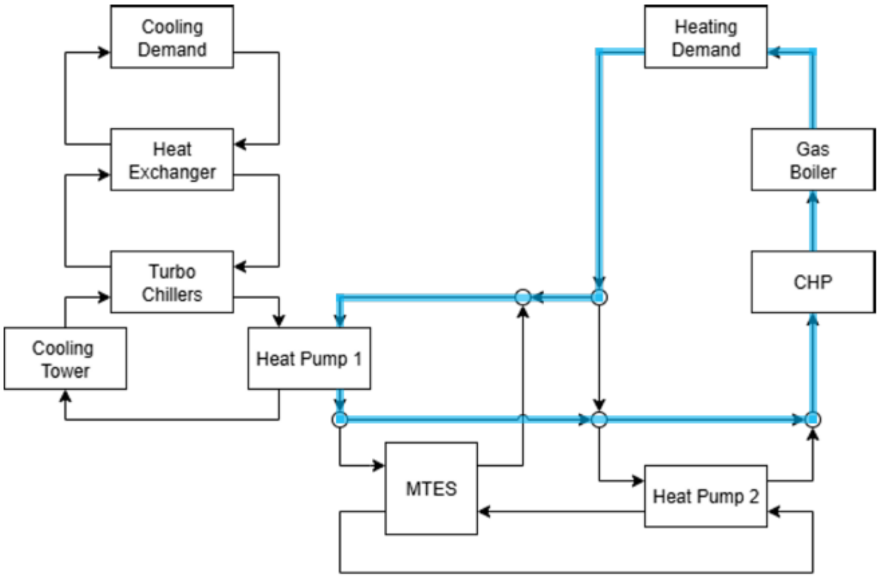


Figure 21: The control strategy for scenario 3.

The fourth and final scenario, visualised in Figure 22, describes the situation in which heat pump 1 is operating at full capacity and the MTES is being discharged. This occurs when the if-statement containing the equation $\dot{Q}_{Demand,Heating} - \dot{Q}_{CHP} - \dot{Q}_{HP1} > 0$ holds true. When this is the case, the flow is directed through heat pump 2, where the MTES can be discharged. This discharge can only take place if there is a sufficient temperature difference between the evaporator and condenser temperatures of heat pump 2, and only for as long as the MTES temperature is above the user-defined minimum.

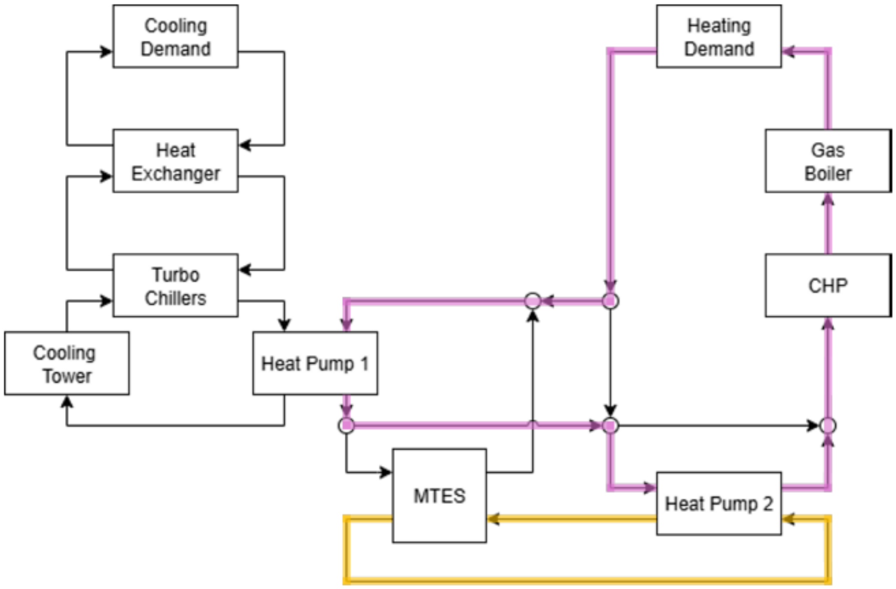


Figure 22: The control strategy for scenario 4.

5. Monitoring System

5.1. Long-Term Monitoring

Long-term monitoring focuses on the in-situ properties of the MTES system via downhole data logger and water sampling at different times, respectively. Initial sampling took place after drilling and completion of well P2. The following in-situ parameters were monitored:

- Temperature: 12.6 [°C],
- Pressure: 1.3 [mH_2O],
- Conductivity: 860[µS/cm],
- pH: 7 [-],
- O_2: 5.0 [mg/L]

The pressure and temperature logger data from 12/2024-12/2025 showed constant values throughout the one-year monitoring interval.

In addition, seismological impacts were measured and evaluated by a seismological monitoring network containing six adjacent monitoring stations, with one close to the demo site (Figure 23). The seismographs did not indicate any events caused by drilling operation.

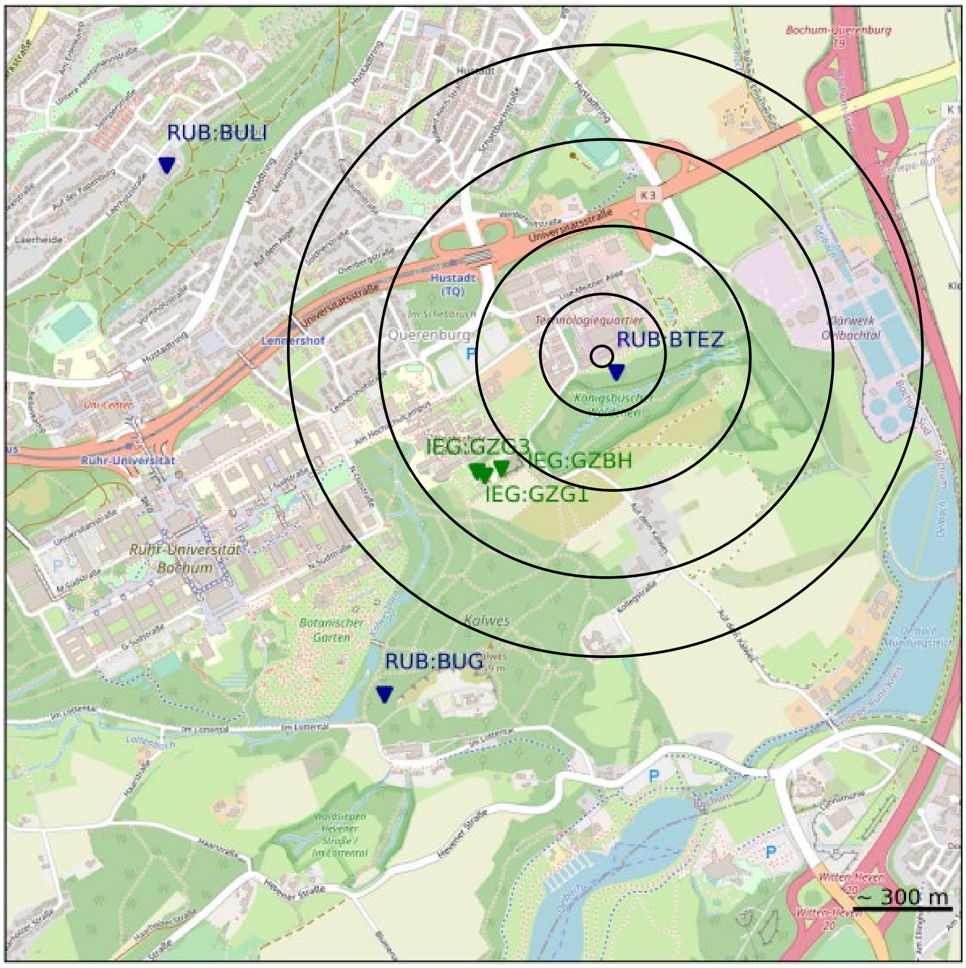


Figure 23: Seismological observation network belonging to RUB (in blue) and F-IEG (in green)

In the future, well pump performance monitoring will be carried out. Therefore, the intended 8”-submersible pump will be equipped with a PT-100 sensor cable to record the heat emission during operations.

Additionally, an external sensor-sub is under development, which will be attached to the downhole pump, based on acoustic emissions (for more information see D3.6 pp15-16).

5.2. Hydrogeological Monitoring and Water Quality

Regarding the reservoir, the follow-up of (bio)geochemical reactions will be the main part of the monitoring to understand the thermo-hydrogeological behaviour of the intended MTES. The topic of corrosion related to water quality in MTES has been raised during the PUSH-IT Project, since former mine galleries might be supported by metal reinforcement. In Bochum, it’s unclear whether the support beams were made of wood or iron.

To address this possibility, baseline monitoring is necessary. This was conducted via sampling of undisturbed water from the mine reservoir (Figure 24).

(Bio)geochemical phenomena might lead to some scaling in wells, which could be detrimental for long-term operations.

Therefore, laboratory analyses on major, minor and trace elements (Ca, Mg, Na, K, Cl, S, Si, Li, F, Br, Mn, Fe^{total}, Al), phosphate (PO4) and nitrate (NO_3^{-1}) have been taken, a fouling risk assessed based on water chemistry and a PhreeqC simulation was made.

Figure 24: Mine water sampling of MTES borehole P2 (02/25)

As a result, the overall tendency to foul is low if oxygen ingress is prevented. Only aluminium and iron are above detection limit. Sulphate as a possible biofouling indicator has been detected.

To counteract possible scaling issues on the heat exchanger, a Ni-Cu-P-PTFE coating is recommended. A pre-treatment of the mine water is not necessary if maintain flow rates > 1 m/s in the heat exchanger.

To conclude, the Mansfeld site shows low fouling potential. Simple design measures and optional coatings can ensure efficient heat exchanger operation without frequent cleaning.

6. Public Engagement, Social Benefits and Risks

6.1. Public Engagement

Public and scientific engagement focused on the MTES technology being installed at the Bochum demo site included seminars/webinars, stakeholder meetings, industry and academic conferences as well as public facing activities to target policymakers, industry, academic communities and the general public, contributing to knowledge exchange and capacity building at local, national, and international levels.

Seminars and Webinars

Presentations were delivered in various formats, including: i) A local policy webinar organised by the local conservative party, discussing the applicability of Bochum's MTES experience to regional heat planning, ii) Technical workshops with energy providers and public services at Geothermie-Zentrum Bochum and an internal "Heat Café" session with the UK Mining Remediation Authority, iii) Academic lectures for MSc students and at kassel25 mine water conference.

Stakeholder Meetings

An expert meeting at the Fortuna mine gathered over 20 representatives from authorities, ministries, and agencies to explore legal and technical options for using abandoned mines as heat sources. Fraunhofer IEG and the University of Mainz presented lessons learned from mine water projects.

Industry and Academic Conferences

The project was featured at major events like i) GeoTHERM / GEOTHERMICA UTES Symposium (Offenburg, Germany), ii) International Mine Water Association Conference (2024 in USA, 2025 in Portugal), iii) International Energy Agency (IEA) Geothermal Mine Water Symposium (UK), including presentations and posters on MTES developments in Bochum and Cornwall. Furthermore, participation at reception of the German Mining Association (Berlin) for informal discussions on Underground Thermal Energy Storage (UTES) as well as DGK Conference (Frankfurt) with a poster presentation by an MSc student during an interactive poster session, receiving technical feedback.

Public-Facing Activities

i) A 15-minute presentation during Climate Week at the theatre in Bochum, reached around 200 attendees and led to new research connections, ii) Fence banners with accessible information for adults and children (with interactive elements like QR code or experiments for home) were installed at the drilling site, iii) A radio interview at the PUSH-IT drilling site informed a wider audience about MTES technology.

Additional Engagement

The team supported the preparation of the PUSH-IT engagement catalogue, contributed to expert interviews, and began planning stakeholder round tables and focus groups for 2026.

6.2. Regulation and Governance

Regulation of HT-MTES in Bochum

Regulatory oversight in Germany is decentralised, with national laws setting standards and state authorities managing implementation.

For Bochum, the permitting process involves several frameworks:

Water Legislation: Activities affecting groundwater require notification and approval under the Federal Water Act (*Wasserhaushaltsgesetz – WGH*) and NRW Water Resources Act (*Landeswassergesetz – LWG*). The Lower Water Authority must be informed of any potential impacts on groundwater quality and flow.

Mining Legislation: Drilling deeper than 100 m and across multiple properties requires authorisation under the Federal Mining Act (*Bundesberggesetz – BBergG*). In NRW, drilling activities must be registered via the online platform www.bohranzeige.nrw.de/online/. The Mining Authority (Department 6 Mining and Energy, Arnsberg District Government) supervises drilling and addresses issues such as methane hazards.

Geological Data: All geological information collected during investigation and construction must be submitted within three months to the Geological Survey of NRW, as required by the Geological Data Act (*GeolDG*).

Additional agreements were secured with land and mine owners and the Ruhr University as the main beneficiary. A supplementary agreement was required for the borehole location.

To reduce bureaucracy and streamline future geothermal projects, Germany has recently introduced the **Geothermal Acceleration Act (Geothermiebeschleunigungsgesetz) (GeoBG)**, which amends existing laws (BBergG and WGH) to simplify and accelerate permitting for geothermal and heat storage systems.

These recent developments in German legislation include important changes to geothermal and UTES projects. First, the limit between near-surface and deep geothermal energy has been updated and modified, from 100 to 400 m depth. This has led to a change in the scope of application of the Mining Law (BBergG) for geothermal projects.

In addition, some amendments have been introduced that clarify the regulation relevant to underground thermal energy storage, in which the application of the Mining Law has been focus of some discussion. Previously, and in some circumstance in which more heat was injected than extracted, i.e. there was not net geothermal heat extraction and the storage medium was classed as water (not brine with higher salt content), it was decided that only the Water Law was applicable. The new Geothermal Acceleration Act has introduced an amendment that clarifies the application of the Mining Law ("*…a heat storage facility located at a depth of 400 meters or more is considered an underground storage facility, even if the heat is stored in a water-based manner.*"), and therefore from now on the BBergG applies to MTES projects deeper than 400 m that use water as storage medium.

Regulatory Interviews

In March 2025, the British Geological Survey (BGS) visited the Bochum site to conduct the site regulatory interviews, gather additional information on the regulation of HT-MTES in Bochum, and participate in the Winzer meeting.

The objective of the interviews with developers and regulators is to collect specific information about the regulatory landscape at each project site to compliment the desktop review of regulations submitted as deliverable 2.1 (D2.1: "Review of State of the art in geothermal regulation and regulatory barriers and opportunities in different countries, relevant for technologies in use").

More specifically, it is intended to identify both, the key barriers for UTES and HT-UTES project development, and any specific factors that are considered facilitators.

The interviews have been transcribed and anonymised, and are currently being coded and analysed, extracting key outputs for the comparison and set of recommendations that will be part of the final WP2 deliverable "D2.5: Final work package report summarizing societal aspects of geothermal underground storage"). Outputs from the interviews will also be used for the spatial multi criteria analysis (SMCA) in WP4.

The first initial results were submitted and have been presented in the International Mine Water Association conference in Braga (Portugal) and the European Geothermal Congress 2025 in Zurich (Switzerland) (Gonzalez Quiros et al., 2025a, b) and submitted for presentation in the World Geothermal Congress 2026 in Canada ("Evaluating Regulatory Frameworks for High-Temperature Energy Storage in Europe within the project PUSH-IT").

6.3. Techno-Economics

For the techno-economics, the levelized cost of heat (LCOH) was analysed at different lifetimes for varying discount rates. The progression of the resulting LCOH values can be seen in Figure 25. Every LCOH curve starts at the same point, regardless of the discount rate. This is because, at time zero, only the capital expenditures (CapEx) play a role, and this is the same for every scenario. As time progresses, the CapEx is spread out over time as it is a one-time expense. This means that the LCOH decreases over time, explaining the downward slope in the first 10 years.

However, the yearly operating expenditures (OpEx) and heat production also play a role from the first year onwards. This becomes increasingly visible after the first 10 years; the CapEx no longer plays a significant role in the LCOH, and the OpEx combined with heat production dominate. This causes the LCOH value lines to flatten out and, by the end of the graph, to almost form a horizontal line. It is important to note that if a system has a certain lifetime, the LCOH value at that point in the graph will be the same for every year of the system's lifetime.

Corresponding to Figure 14 (concept 2), the values for the LCOH at different lifetimes and for different discount rates vary from ca. 48 €/MWh (best-case) to 67 €/MWh.

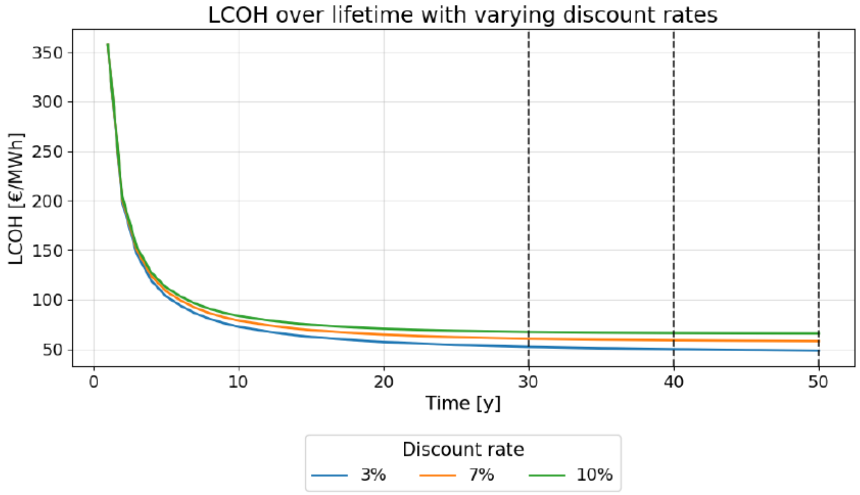
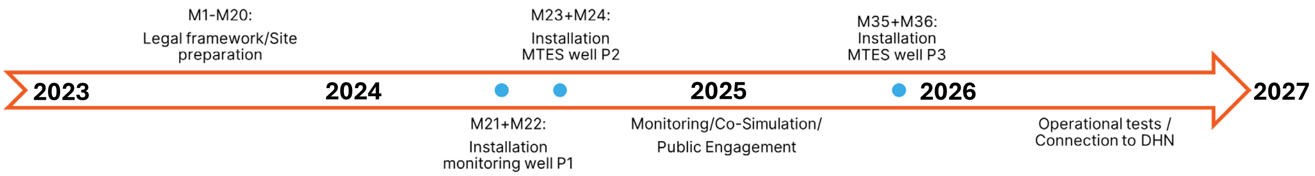


Figure 25: The Levelized Cost of Heat (LCOH) for different discount rates. The discount rates are visualized by different colours, whereas different lifetimes are visualized by different vertical dotted lines

7. Tasks and Plan of Action

Status / activity milestones are:

- Project preparation and legal framework done [M20].
- Drilling and completion of the pilot borehole P1 as monitoring well [M21-M22]
- Drilling and completion of the MTES well P2 [M23-M24]
- In-situ tests (geophysical logging, camera runs, microbiological and geochemical sampling [M23-M36]
- Drilling and completion of the MTES well P3 [M35-M36]
- MTES operational performance tests [M37-M45]
- Monitoring Recovery and Connection groundworks to the technical centre [M46-M48]



8. Risks and Mitigation

Table 3: Updated foreseen and unforeseen Risk management matrix for Bochum with risk description and mitigations measures associated

Occurrence	Description level of (i) likelihood, and (ii) severity	Mitigation
No	Site not ready for MTES tests and implementation	Demo Site has been already erected with two mine water wells. With the installation of two further wells at the northern part of the demo site, the MTES is going to be enlarged to the maximum possible distance of injection and production wells.
Yes	DH network controller testing: unwillingness of building owners to participate (i: high / ii: medium)	Due to contractual and technical reasons, control of building set points is not possible. A virtual test environment, based on the co-simulation results, will be produced.
No	Permissions not obtained for testing, and/or operation.	Permit for circulation test approved.
No	Financial: associated projects for demonstration and follower sites are postponed or not realised.	Funding is assured and material as well as personal costs are covered, and material will be bought. Smaller buffers in terms of the operation phase (e.g. buying a new drill bit) are included (20% for uncertainties/contingencies). For the sites with associated projects project funding is already in place. Mitigation is via the use of demonstration and follower sites, such that activities can be moved from one site to another within the project to still achieve the aims.
No	Administrative/financial: tendering procedure failure (i: low / ii: low)	Learnings from D2Grids/DGE Rollout within Fraunhofer guidelines in terms of tendering.
No	Local communities uninterested in engagement activities about the demonstrator site. (i: low / ii: medium)	Engagement plans will follow co-creation design principles to establish needs and wants of local communities. Due to existing plans (Dannenbaum, Heat store pilot site) in Bochum for the pilots, social stakeholders are already aware, and partners have access to them. Preparatory work, while developing this proposal by leaders of WP2, resulted in an initial engagement with stakeholders. Mitigation via identification of groups who have already engaged in energy system development at each demonstration.
No	Limited material / equipment availability due to strained international market situation (i: medium / ii: medium)	Time buffer considered in project time planning, timely ordering of equipment.
No	Price increases make budget unrealistic at time of implementation, e.g. for manufacturing pipes (i: low / ii: medium)	Go / no-go moment for components, so that budget can be transferred to standard components and overall objectives and results can be achieved, re-adaptation of the workplan accordingly.
No	Co-simulation computational time too long (i: low / ii medium)	Simplify the subsurface model to enhance integration in the DHN.
Yes	MTES reservoir property uncertainties	MTES reservoir flow properties are critical for project success and have been mitigated via investigations

Occurrence	Description level of (i) likelihood, and (ii) severity	Mitigation
	(i: high / ii: high)	carried out in the recent HEATSTORE project. Some uncertainties in terms of mine water drainage remain. Hydraulic testing of the system will find this out.
No	Drilling / Workover failures (i: low / ii: low)	First three boreholes drilled without any failures.
No	Undetected heat losses occur (i: medium / ii: high)	All sites have extensive monitoring and simulation activities. In the event of poor recovery efficiency due to heat losses that are not detected additional analysis and simulations will be carried out to identify the source of these losses.
No	Aquifer contamination / Aquifer temperature threshold (i: low / ii: medium)	First mine water samples didn't indicate any contaminations. All limit values are in accordance with Section 7, Paragraph 3 of the Bochum Wastewater Statute.

9. Conclusion

Despite incurring delays due to the drafting of all necessary contracts and agreements taking longer than anticipated, the project's general schedule of Task 1.3 is still on track. Parallel to the final signature between F-IEG and RUB (affiliated partner), the drilling and demonstration site was prepared within just a few weeks, and substantial progress has been made afterwards (drilling, geophysical logging and imaging runs, Huisman Composite Tubular (HCT) installation according to WP3.1 together with Huisman Equipment B.V.).

As a result, three boreholes have been completed and will be monitored during and after hydraulic tests.

During the exploration phase in 2024, several experiences and lessons-learned were obtained, which will be applied for the future, so that drilling and installation risks could be distinctly reduced in comparison to 2024 (for example, additional drill collars have been bought in the meantime, which was one of the major lessons-learned). Adjusting and improving the installation procedure, (the bottom-hole-assembly) has led to successful results for drilling the MTES wells P2 and P3.

In combination with upcoming hydraulic circulation tests, we'll achieve the next milestone. If positive results achieved, the Mine Thermal Energy Storage (MTES) technology can be applied and further tested at the demo site, respectively.

Given the current progress at the Bochum site, we are confident that we will be able to achieve most of our objectives within the project timeframe. However, the MTES performance assessment will be shorter than expected when compared to the proposal.

References

Gonzalez Quiros, A.; Stewart, M.; Olver, T; Klein, S.; Mugova, E.; Abesser, C. (2025): Challenges and Opportunities for High-Temperature Mine Thermal Energy Storage with Focus on Regulatory Barriers for Implementation. – In: Valente, T., Mühlbauer, R., Ordóñez, A., Wolkersdorfer, Ch.: International Mine Water Association Conference – Time to Come. – p. 383 – 387; Braga (International Mine Water Association).

Gonzalez Quiros, A.; Stewart, M.; Abesser, C. 2025 Untangling the Regulatory Barriers for High-Temperature Underground Thermal Energy Storage within the PUSH-IT Project. In: Shaping the Future : European Geothermal Congress 2025, Zurich, Switzerland, 6-10 Oct 2025. European Geothermal Congress.

Klein et al. D1.1 Workplan for Delft, Darmstadt, Bochum, Berlin and Litoměřice activities: drilling, monitoring, service plant, integration/control, community engagement plan, permit (2023)

P.J. Vardon et al. D3.6 Workplan for cross site activities: co-simulation, control, push-pull tests and water quality (2024)

Spengler: Co-Simulation of a District Heating and Cooling System in Combination with Mine Thermal Energy Storage: A Case Study in Germany. TU Delft (2025)

The EU aims to have a net-zero greenhouse gas (GHG) economy by 2050, with 55% reduction on 1990 levels by 2030. At present, heating and cooling represent around 50% of the final energy demand in Europe and are mainly supplied by fossil fuel derived energy. It is therefore essential for heating and cooling to decarbonise to achieve EU ambitions.

A challenge for decarbonizing heat systems is the size of the seasonal mismatch between demand for heat and heat generation from sustainable sources – this mismatch is much larger than the equivalent intermittency in electricity supply and demand. The two main solutions to address this mismatch are: (i) to install a large capacity, so that peak demands can be met even at low production levels; or (ii) to store energy for later use if it is not needed at time of conversion. Many sustainable heat supply systems are characterised by high capital expenditure and low operational costs. Therefore, an installed capacity tailored at peak demand is not cost effective, while extending the annual operation period is advantageous for meeting energy needs, reducing levelized cost of energy (LCOE) and decarbonisation. Optimal utilisation of sustainable heat requires storing large amounts of heat to account for seasonal supply and demand fluctuations. Various technologies have been proposed for large-scale heat storage in geothermal reservoirs and low temperature storage is routinely applied. PUSH-IT focuses on extending storage temperature ranges to high temperatures. We will tackle remaining barriers, demonstrate applicability, increase public engagement, and optimise and de-risk operations. We will showcase three technology options that are fit for a wide variety of geological conditions covering most locations in Europe.

PUSH IT

Funded by
the European Union