Interreg North-West Europe
EUROPEAN UNION

DGE-ROLLOUT

Best-practice guide

WP Invest - Deliverable 1.4.1

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June 2023

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Introduction

Deliverable 1.4.1 of WP Invest "Best-practice guide" is defined as follows: identify best-practice strategies applied to urban district heating networks for cascading and thermal storage systems.

It describes the steps to achieve a successful installation of a cascading system that feeds geothermal heat into the district heating grid and exploits a seasonal thermal storage system as heat source, such as the system in Bochum, Germany, which was developed throughout the DGE-ROLLOUT project (Fig. 1).

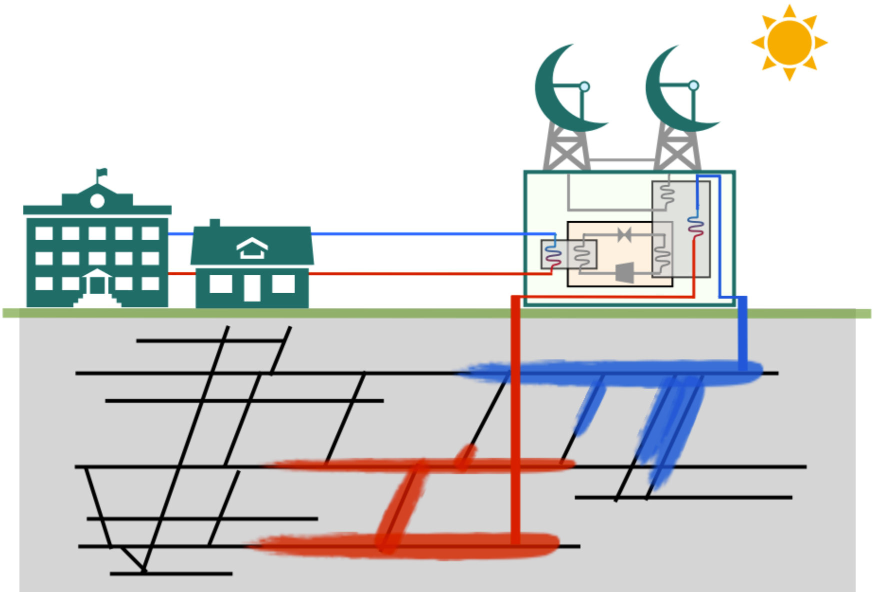

Figure 1. *Scheme of HTHP pilot plant in Bochum*

Steps for the development of the pilot plant

The pilot plant on the premises of Fraunhofer IEG (Fh-IEG) in Bochum operates seasonally by injecting heat into a flooded mine by means of solar thermal collectors in summer and heat extraction during winter, using a high temperature heat pump (HTHP) system to generate heat for the local district heating (DH) grid.

It has to be noted that the heat injection portion of the plant was previously developed within the HeatStore project (HEATSTORE | Geothermica) from 2018 to early 2021.

The scope of the HeatStore project included the numerical modeling of the heat source, selection of the best drilling locations for injection, production and monitoring wells, drilling into the unused flooded mine, installation of the solar parabolic trough collectors, and tests such as pressure, pump and heat injection.

The DGE-ROLLOUT project ran from 2018 until 2023 and the development in Bochum started in the third quarter of 2019. Several steps were taken to install the pilot plant using the HTHP system with a geothermal heat source connected to the DH. The main steps are reported in Fig. 2.

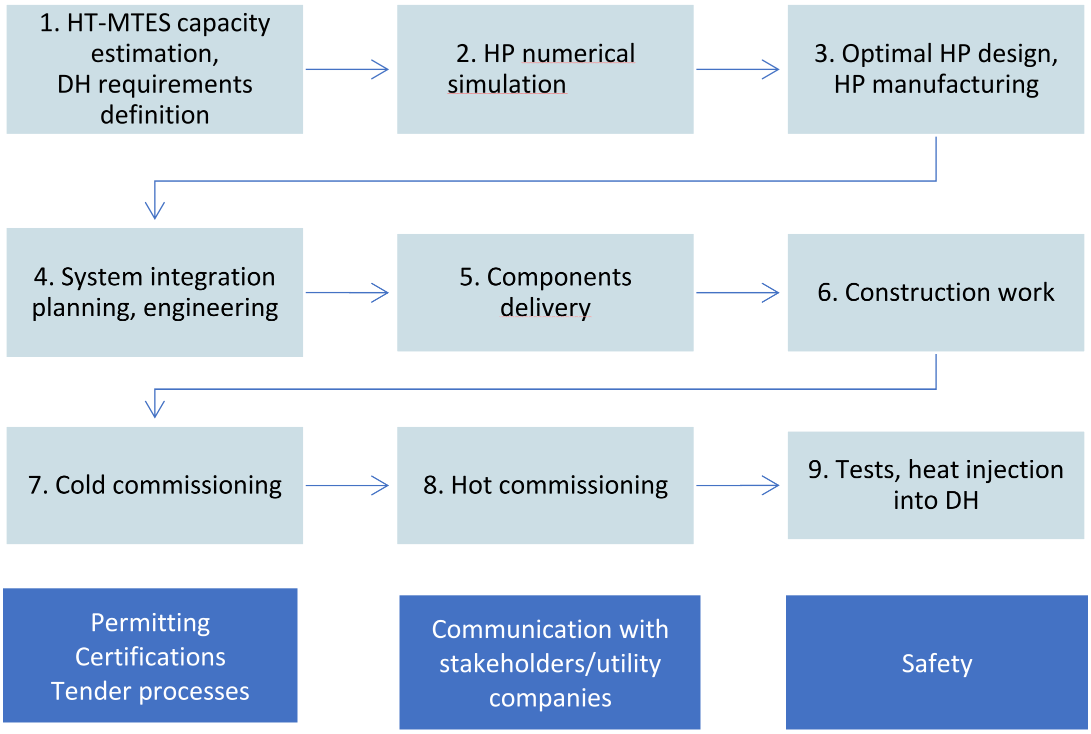

Figure 2. *Scheme of the different steps followed for the development of the plant*

The initial step of the project was the evaluation of the high temperature mine thermal energy storage (HT-MTES) capacity and the requirements of the district heating grid. By knowing the heat source and heat sink of the HTHP, it was possible to define the process parameters of the HTHP itself.

Numerical simulations were conducted throughout the project development to find the best heat pump solution and estimate its theoretical performance.

The best HTHP solution was then fully defined, selected and manufactured, followed by the planning of the system integration, i.e. the connection of the heat pump with HT-MTES and DH.

After the delivery of the components the installation began. Once the construction work was completed, cold and hot commissioning were performed. The final step was to test the entire system and start injection of heat into the DH.

Tasks that were not strictly technical but of fundamental importance for the success of the project were permitting, certifications and tender processes, communication with stakeholders such as utility companies and safety procedures.

1. HT-MTES capacity estimation; DH requirements definition

Timeline: August 2019 – October 2019

Determining the preliminary general requirements and constraints of the system is the first and a highly relevant step to understand which equipment can be installed.

In particular, the **estimation of the mine capacity**, was the most important step in dimensioning the heat pump unit. Specific details are given in several papers, including *Hahn et al. 2019 and Passamonti et al. 2022.*

Whereas for the majority of power plant installations the heat source is not the hardest constraint, but the required heat production is, in the specific case of the plant developed in this project there were open questions about the heat source. Indeed, the HT-MTES is a pilot site with a finite heat source capacity. Furthermore, the heat injection section of the plant was developed partially in parallel with the planning of the heat extraction. Therefore, the heat source capacity had to be carefully estimated with the information available at that time, considering the possibility of installing a flexible system.

From the estimation of the HT-MTES storage capacity, it was possible to determine the maximum thermal power that can be produced by the system. Assuming a reasonable coefficient of performance (COP) and annual operating hours, the heat pump system can have a capacity up to 500 kW, with partial load playing an important role, since partial load tests may be required initially to verify the performance and behavior of the HT-MTES.

The operating temperatures of the HT-MTES were known: the minimum is the unheated temperature of the mine and the maximum allowable one is the result of the permitting processes of the water authorities.

The power to be injected into the DH grid did not constrain the system in this case, since the order of magnitude of the installation was negligible for the utility company compared to the rest of the grid.

The **supply temperature range required by the DH grid** was one of the main aspects that led to the plant being defined as a pilot site. In heat pump technology, the standard supply temperatures reach up to 90°C, and many HP units up to this temperature are commercially available. However, in the case of the DH grid of Bochum south, the heat pump system must supply pressurized water at a temperature of 80°C to 120°C, with higher temperatures required on the coldest days of the year.

This chapter describes the procedure to start the planning of the developed pilot plant (Fig. 3), and the most common procedure (Fig. 4) for the installation of a general plant.

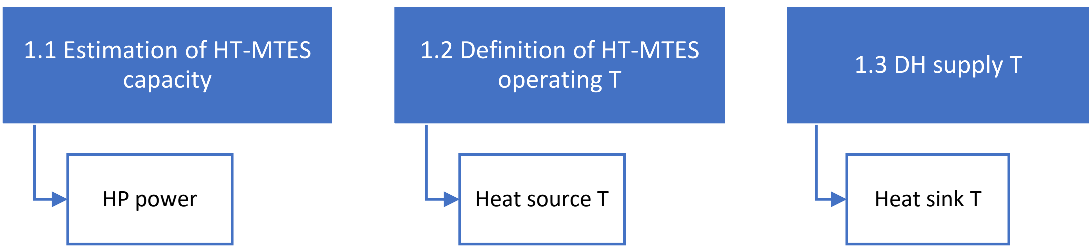

Figure 3. *Scheme of sub-steps of step 1 for the development of the project plant (T=temperature)*

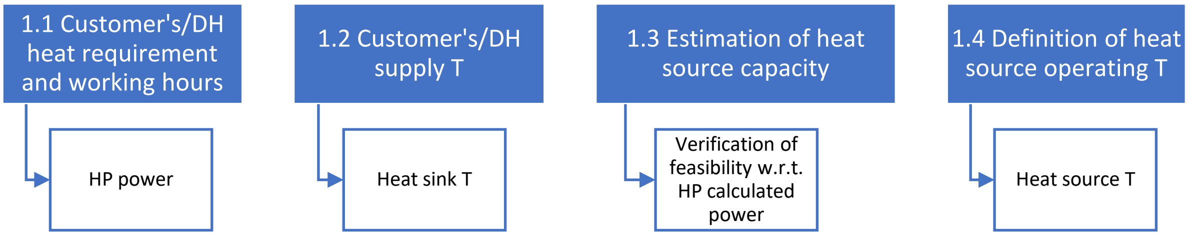

Figure 4. Scheme of sub-steps of step 1 for a general plant (T=temperature)

2. HP numerical simulation

Timeline: October 2019 – end of the project

Numerical simulation was implemented throughout the majority of the project with different goals and by different parties, i.e. Fh-IEG and suppliers.

The initial simulation was carried out to determine the best heat pump solution and refrigerants according to the constraints of the project. One example is the pressure (see pressure-enthalpy diagram for an ammonia heat pump and the variation of its COP with the heat source temperature, Figs. 5.a, b).

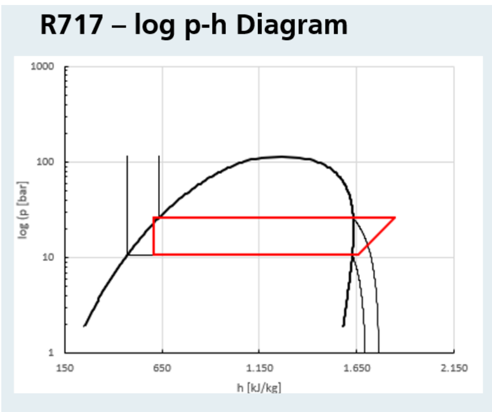

Figure 5.a. P-h diagram R717 (Matlab, Coolprop)

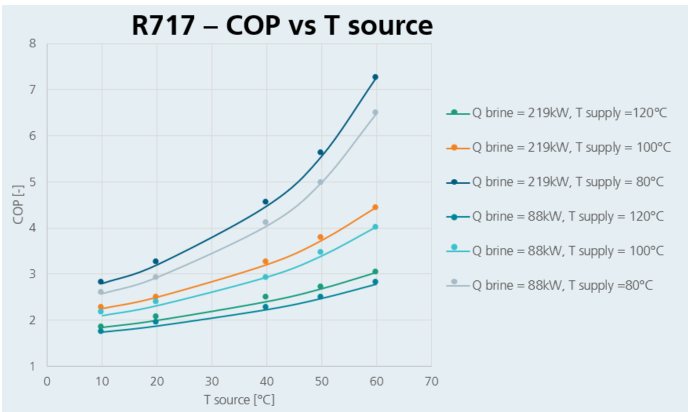

Figure 5.b. COP vs. T source R717, varying Q brine, T supply (Matlab)

In cooperation with the heat pump manufacturer, these models were used as basis to dimension the individual components and their respective performances.

Simulation tools were used to dimension the hydraulic and control system surrounding the units in collaboration with the engineering, procurement and construction (EPC) company and its sub-suppliers.

In addition, a digital twin of the units and the plant was prepared by Fh-IEG (Fig. 6):

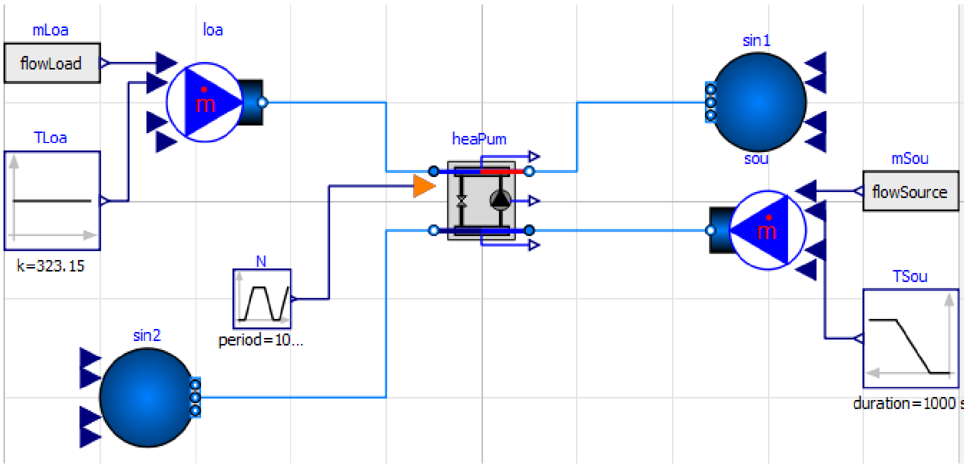

Figure 6. Digital twin of the ammonia unit (Modelica)

Various developed models were presented at conferences and stakeholder meetings to promote the project.

3. Optimal HP design, HP manufacturing

Timeline:

- Contact possible HP manufacturers: October 2019 – January 2020
- Preparation of tender based on evaluation of manufacturers and possible systems: October 2020 – May 2021
- Tender: May 2021 – June 2021
- Tender HTHP evaluation and award: July 2021
- Commissioning of HP production: August 2021
- Delivery of the units on site: Oct 2022

For this project, especially for the HTHP technology, the main constraints of the system are the power that can be extracted from the HT-MTES and the supply temperatures needed to supply the DH grid.

Literature reviews, market analyses and the participation in conferences of the geothermal sector were fundamental to understand which manufacturers would be interested in collaborating on the development of a pilot plant for a HTHP system.

Several contacts were made leading to the optimal and only possible solution: a two-stage heat pump system with ammonia and butane as refrigerant. As reported by Passamonti et al. 2022, the proposed solution was developed by the manufacturer in close cooperation with Fh-IEG and meets all requirements.

In October 2022, the units were delivered on site ready to be installed. The timing of this step largely overlapped with the covid pandemic, which had some impacts on the timeline but did not affect the final outcome.

4. System integration planning, engineering

Timeline:

- Planning, engineering by Fh-IEG: May 2020 – May 2021
- Contact with possible EPC companies: August 2020 – May 2021
- Preparation of tender based on evaluation of manufacturers and possible systems: June 2021 – November 2021
- Tender 1: November 2021 – December 2021
- Tender 1 evaluation: January 2022
- Tender 2: January 2022 – February 2022
- EPC tender evaluation and award: March 2022
- Detailed engineering by EPC: April 2022 – Nov 2022

Planning of the system integration was done in several steps (Fig. 7) and in cooperation with contractors and sub-contractors.

The piping and instrumentation diagram (P&ID) was initially designed by Fh-IEG to highlight the functionalities of the plant, i.e., the different functions that the plant is required to carry out. One example is the extraction of heat from the HT-MTES through the HTHP and feeding it into the DH. Moreover, a large water storage tank can be used to simulate the mine for a working day by increasing the temperature with solar collectors and then using it as heat source for the heat pump. An intermediate water loop was also designed for the HT-MTES to decouple the flow rate from the mine, and to avoid precipitation and corrosion on the evaporators of the heat pump units. Furthermore, dry coolers that were already present were integrated into the system for testing purposes and redundancy.

The reported included functionalities, along with other aspects such as boundary conditions, were included in the initial P&ID as a starting point for detailed engineering. The more accurate the P&ID and the planning are during the first stages of the project, the faster the following steps are.

Several companies were contacted for implementing the system integration between the heat pump system and HT-MTES and DH. It was of relevance to contact companies that are interested in the decarbonization of the heating sector and have experience in cooperating with specific heat pump manufacturers. However, post-pandemic availability of companies for construction was generally low and the schedules often did not match the project timeline.

Detailed engineering was performed with the support of the EPC company and its sub-partners. The P&ID was completed with further elements such as safety, monitoring and control strategies. The components were dimensioned and procured, and additional sub-suppliers were individuated for the construction phases.

In parallel, detailed planning was carried out by Fh-IEG with regard to facilities such as water, electricity and earthworks. In the case of the project, electricity was not available on site for either construction nor operation of the plant; water sources for the loops and tanks were planned, i.e. it was determined how to fill which loop; earthworks to install the concrete foundations for the units as well as to lay the pipes underground were planned.

The process is summarized in Fig. 7:

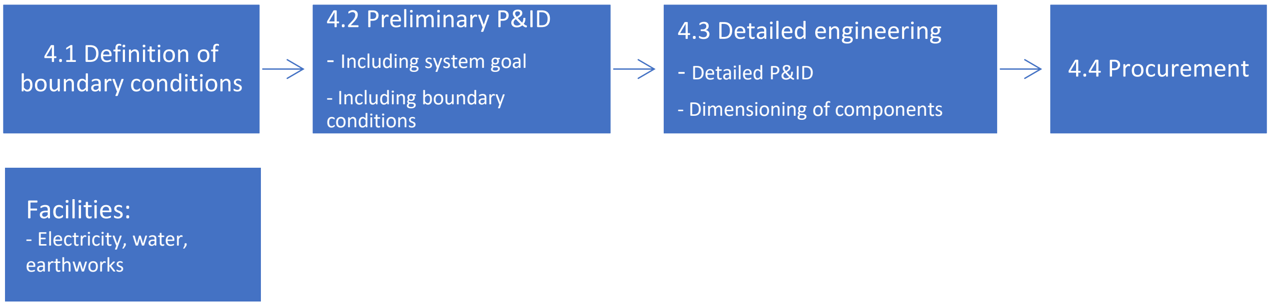

Figure 7. *Processes for step 4*

5. Components production and delivery

Timeline: June 2022 – April 2023

The components of the heat pump system were procured shortly after the tender was awarded, and as expected the production of the units took approximately eight months until they were delivered in October 2022 (Fig. 8.a). Components of the hydraulics of the units, measurement and control system were delivered from June 2022 onwards (Fig. 8.b). After preparatory work such as cutting trees and leveling the ground, the foundation was built at the plant location in early 2023 (Fig. 9).

Figure 8.a. *Delivery of the units*

Figure 8.b. *Delivery of hydraulic components*

Figure 9. Construction of the foundation

The components for connecting the units to the HT-MTES and DH were delivered during the first quarter of 2023. The parts were procured and delivered in an order that was most convenient for the construction (Fig. 10). Extra time was accounted for damaged or defective goods as well as for overall delays in production and distribution chain. Delivery times, especially for heat exchangers, pumps, and electronic components, could not always be estimated by the manufacturers as a result of the pandemic.

In Fig. 10 is illustrated the followed order of procurement and delivery of the components.

***Figure 10.** Process for step 5: Order of procurement and delivery of the components*

6. Construction work

Timeline: December 2023 – April 2023

The construction work on site lasted for about four months and followed several steps.

Initially, the construction work took place inside the two containers in which the connections to the heat source and heat sink are located. At the same time the piping between the two units was welded (Fig. 11.a).

Once the concrete plates were positioned, the two containers, the two units, the dry coolers, the buffer tank between the units and the storage tank were successively positioned at their final location (Fig. 11.b). The electricity needed for the construction was brought on site.

Figure 11.a. *Construction work in containers*

Figure 11.b. *Final positioning of components*

The construction of electric cabling and cable routes continued, in parallel with the earthworks to lay the pipes from solar container and mine to the location of the units (Figs. 12.a, b).

Figure 12.a. *Cable routes and cabling*

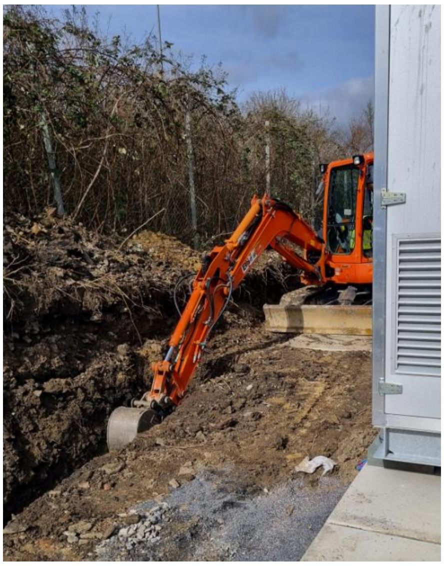

Figure 12.b. *Earthworks*

The welding, installation of heat exchangers, pumps, vessels, valves and sensors, also proceeded outside the containers (Fig. 13). Furthermore, the procurement of electricity for operating the units was performed on site.

Figure 13. Hydraulic connection between the units

While trace heating and insulation started in the locations of the plant where they were needed, welding started in the tunnel which connects to the DH grid. Due to time constraints, the insulation in the tunnel started as soon as possible (Figs. 14.a, b, c).

Figure 14.a. *Trace heating*

Figure 14.b. *Insulation*

Figure 14.c. *Insulated piping in DH tunnel*

Earthworks were performed to connect the pipes running from the tunnel towards the corresponding container and heat exchanger. The pipes were laid, covered with trace heating and insulated (Fig. 15.a, Fig. 15.b).

During the final phases of the construction work, the programmers on site started to set up the control and monitoring system.

__Figure 15.a.__ District heating connection

__Figure 165.b.__ Connection to main DH pipes

A summary of the stages of construction work for the development of the plant is shown in *Fig. 16.*:

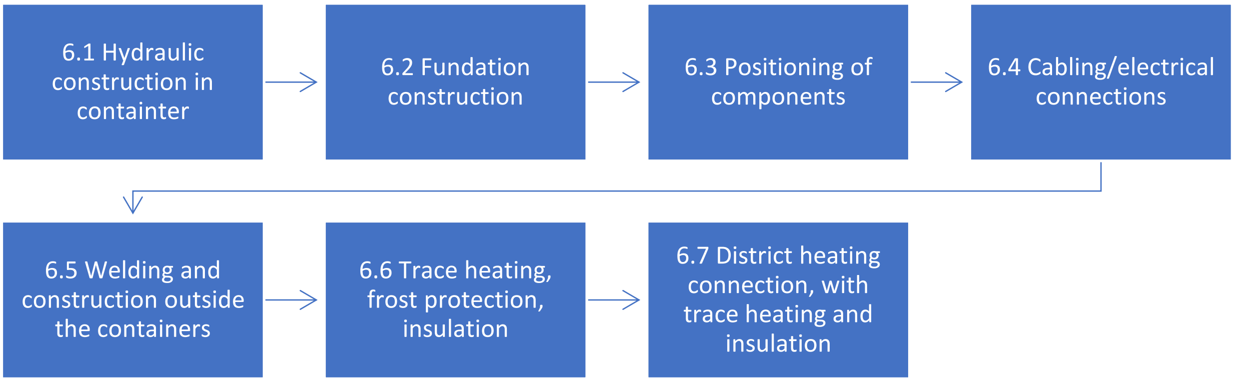

__Figure 176.__ Process for step 6

7. Cold commissioning

Timeline: February 2023 – April 2023

The cold commissioning included pressure tests, loop checks, X-ray of the pipes, filling of the system and mechanical safety checks and was performed on the different loops that are part of the system: mine water loop, heat source intermediate loop, heat sink intermediate loop with bypass heat exchanger and dry coolers loop, intermediate loop of the units, and district heating connection.

The cold commissioning was partially carried out in parallel with the construction work since it was possible to start the process for each loop as soon as the loop was installed.

8. Hot commissioning

Timeline: May 2023

The hot commissioning consisted of sensors, pumps calibration, implementation of the control system, running the units at different conditions, and electric/electronic safety checks.

As soon as the units started running, the entire control system of the units and the surrounding system had to be finely tuned. This process is the final step of the commissioning of the plant and a delicate procedure. In this phase, the functionality of the pumps and sensors can be verified and it can be determined whether the installation and planning have been performed correctly.

9. Tests, heat injection to DH

Timeline: May 2023 – July 2023

During and after the commissioning and transfer of the plant to Fh-IEG with all documentation, it was possible to test the units under various conditions for research purposes, such as partial load and 120°C of supply temperature with simultaneous removal of part of the heat. In addition, and this is particularly important for the success of the DGE-ROLLOUT project, it was possible to achieve constant heat injection conditions into the DH grid.

10. Permitting, certifications, tender processes

In addition to the technical aspects for the construction of the pilot site, other elements were required such as permitting, certifications and public tenders.

In Table 1 the main permits needed for the development of the plant in Bochum are summarized. The permits included are the ones obtained during the DGE-ROLLOUT project, which comprises the heat extraction from the mine. Therefore, e.g. drilling permits, are not included.

It is important to note that the permits are site-specific. Nevertheless, the ones listed in Table 1 can be considered as general guidelines. It is necessary to consult legislation to verify how often the permits or certificates have to be renewed.

Table 1. *Permits needed for the development of the plant*

Type of permit	When to be issued	Issued by
Mine utilization	Before planning	Mine owner
Mine water utilization	Before heat injection/extraction in MTES	Water authorities
Cutting trees	Before construction	City of Bochum
Building permit	Before construction	City of Bochum

Driving larger cranes on the streets	Before moving components (two weeks)	City of Bochum
Utilization of the tunnel to connect to the DH: sub-rental contract	During planning	RUB

The main specific certifications that were needed for the project are reported in Table 2.

Table 2. *Certifications needed for the development of the plant*

Type of certification	**When to be issued**	**Issued by**
Expansion vessels/pressurized equipment	Before commissioning	TÜV or DEKRA
Training for refrigerants DGUV 500	Before handling the refrigerants	TÜV or equivalent certified entity
District heating certification	Before planning	Arbeitsgemeinschaft Fernwärme (AGFW)
Safety and health coordination on site (SiGeKo)	Before planning	The construction sites ordinance

Not included in Table 2, but important to be considered for construction, is the manner how to handle used refrigerants. This in particular includes the machine room regulations as reported in the Refrigeration Standard EN 378.

The tender processes, even if they did not concern strictly technical aspects, took up a large part of the duration of the project. Two main tenders were issued with an application period of two months and a one-month review period. In addition, the preparation of the documents needed to open the tender also took up to several months. Once the tender was published, it was not possible to communicate with possible manufacturers, anymore. If there had not been any applicants, the process would have been needed to be repeated. In the case of the project, at least one year was used for the tenders.

The time for tenders therefore needs to be considered in the overall project planning, since it is not negligible.

11. Communication with stakeholders/utility companies

The reduction of CO_2 emissions from the district heating system would not have been possible without the good cooperation with all stakeholders involved.

Whereas in the case of the project in Bochum a surface application was installed and public acceptance was not an issue, the communication with different stakeholders such as utility companies and involved entities and local authorities was fundamental for the success of the project.

Similar applications should consider the willingness and openness of the parties involved to allow the development of a pilot site with its characteristic elements, such as higher operating uncertainties compared to a standard power plant.

12. Safety

Safety plays a fundamental role in all sectors, especially if applied work is performed. The responsible organizations need to be aware about European and local legislations. Furthermore, a specific safety organization chart had to be prepared for each contractor, including the organization commissioning the plant, ideally before the beginning of the project or at the latest during the planning phase. In this way, whereas certain tasks are the responsibility of all workers involved, such as wearing personal protective equipment (PPE) and reminders wear it, others were defined and assigned to specific individuals who are legally responsible for them. Furthermore, a safety and health plan needs to be put in place.

In Germany, in the event that two or more companies perform construction work on the same location or if work is performed above a certain height (above seven meters) or underground (depth exceeding five meters), the commissioner or building owner should have a Safety and health coordination (SiGeKo) as defined by the construction sites ordinance (BaustellV). The SiGeKo needs to have a specific training and experience and should be hired during the planning phase to issue a safety and health plan (SiGePlan) with detailed information on risk assessment and coordination of the safety of the construction site.

In the specific case of heat pumps, safety is often largely related to the refrigerant used, e.g. the directives for the construction of machinery rooms are relevant, as is training on how to handle and store such refrigerants.

Lessons learned

Looking back at the processes and the steps that led to the success of the project, many lessons were learned at the different stages of the project and are here summarized.

The majority of the lessons learned can be used as a tool to optimize the work processes and the project schedule.

In particular, single time slots or time buffers should be allocated to specific tasks and preparatory work should be performed as precisely as possible. In addition, other factors should be considered, such as work simplification or specific local issues such as security.

1. **Time allocation:**

   a. **Tender processes and administrative tasks**
   Tenders and administrative processes take time. For tenders, there should be experience with the process on both the publisher’s and bidder’s side. This allows to open the tender

quickly and avoid having to repeat tenders due to a lack of applications. The same applies to general administrative processes such as offers, placing orders, and requesting invoices. Time must therefore be planned and allocated for these tasks, since the project application phase and the processes should ideally be precisely known in advance.

b. Accounting for delays

The biggest issues with delays during the project were related to the covid pandemic, with unknown delivery times and the repercussions on the market that took place afterwards. However, delays always happen during an applied project. Most of them are unavoidable, and therefore extra time buffers should be considered. Flexibility is a great tool to quickly re-organize and manage operations.

c. Accounting for unusable components

A specific reason for delay is when components are not employable for several reasons such as: Damage before, during or after delivery or installation, or if they were incorrectly delivered or procured. Possible solutions include: keeping spare parts on hand, selecting manufacturers with quick service programs, and delivery times.

2. Preparatory work:

a. Project overlapping with low risk

Having sufficient data before the beginning of a new project saves time and lowers the risk of failure. This is not always realistic, but it should be possible, even if initial primary data are not available, to estimate the important values with low degree of uncertainty.
Therefore, the projects to be independent enough to continue in parallel.

b. Boundary conditions

The boundary conditions between the different companies and institutions involved need to be defined as early and as precisely as possible. This includes a clear definition of boundary conditions on the P&IDs as well as a specific definition of the boundary parameters by the parties involved in order to clearly define tasks and responsibilities.

c. Initial versions of documents

The initial versions of the different planning documents, such as the P&ID, need to be prepared as definite as possible, even if the detailed engineering process is done by a third party in order to save time during the later, more time-consuming phases.

d. Sound emissions

Both for safety reasons and due to local regulations, sound emissions need to be monitored and must be below a certain threshold. When working with compressors, this should be considered and precautions need to be taken, ideally before the delivery of the system components.

e. **Electricity and location**

Although it might seem trivial, electricity is always needed on construction sites and in different amounts. Flexibility of power supply is important and should be planned before the beginning of the project.

A clear location for the main components at the beginning of the planning helps with electricity connections and cabling.

3. **Others:**

a. **Simplification of work: hiring few main manufacturers/suppliers**

This point depends largely on the structure and competence of the organization. It was observed that having only few suppliers and one company as construction manager simplifies the construction process.

On the other hand, if several companies with different subsets of suppliers are on site at the same time, the coordination becomes more complex in terms of space, time and safety.

b. **Security**

During construction, there are expensive objects on site that need to be secured, in particular high-voltage cables and electronic components. The importance of this point varies locally, but good lighting at night and a camera surveillance system or on-site security guards should be considered.

Recommendations for future large-scale thermal storage systems of 2 MW

The installed system has the capacity of injecting up to 2 MW into the DH and, as it is, can be replicated in different locations. It needs to be considered that certain elements are installed for testing purposes, since this is a pilot site, and the system could be simplified for a rollout of the technology. Furthermore, it is possible to scale-up the system for larger HT-MTES systems by using larger heat pumps. In addition, the HTHP technology is improving rapidly, and it would be possible to use different heat pump solutions for such a system in the future.

Overall, the **recommendations** in the *Lessons Learned* section can be summarized as follows: **Time allocation** for tender processes and administrative tasks, delays and unusable components; **preparatory work**, including overlap with previous projects, boundary conditions, documentation, and specific elements such as sound emissions, and finally other aspects such as simplification of work and security of the construction site.

Conclusions

The development of the heat pump pilot plant was done in several steps and can be generally applied to urban district heating networks for cascading and thermal storage systems. Nine main technical steps are reported, each clearly defined and specified. Furthermore, non-technical steps are defined, such as administrative tasks, communication and safety.

The experiences, lessons learned and recommendations acquired during the project consider a wide range of tasks and steps, since all elements had to be built from scratch for the pilot site. This aspect allows for a generic process that can be repeated and scaled-up at different locations with different cascading schemes and storage systems.

These lessons learned and recommendations can be used as recommendation for the next projects and future plants.

List of Abbreviations

AGFW	Arbeitsgemeinschaft Fernwärme/ District heating consortium
BaustellV	Construction sites rdinance
CO_2	Carbon dioxide
COP	Coefficient of performance
DGE-ROLLOUT	Deep geothermal energy rollout
DGUV	Deutsche Gesetzliche Unfallversicherung/ German statutory accident insurance
DH	District heating
EN 378	Refrigeration standard
EPC	Engineering, procurement, construction
Fh-IEG	Fraunhofer IEG
h	Enthalpy
HP	Heat pump
HTHP	High temperature heat pump
HT-MTES	High temperature mine thermal energy storage
p	Pressure
P&ID	Piping and instrumentation diagram
PPE	Personal protective equipment
Q	Thermal power
R717	Ammonia
R600	Butane
SiGeKo	Safety and health coordination on site
SiGePlan	Safety and health plan
T	Temperature
WP	Work package
w.r.t	With respect to

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