USES4HEAT

D4.1 USES4HEAT

Baseline monitoring Oslo Demo site

CELSIO

Co-funded by the European Union

D4.1 USES4HEAT baseline monitoring Oslo Demo Site

Deliverable number	D4.1
Responsible partner	CELSIO
Due date of deliverable	2025-01-31 (first draft)
Actual submission date	2025-01-26 (first draft) 2025-05-15 (second draft)
Version/document history	1
Authors	Fredrik Thorbjørnsen
Reviewers	Fredrik Thorbjørnsen (CELSIO), Willem Mazzotti (BD), Silvia Trevisan (KTH), Sverre Tragethon (Hallingplast), Pontus Jansson (ABS)
Work package number and title	WP4 Oslo demo site
Work package leader	Celsio
Work package participants	KTH, CELSIO, BD, ABSOLICON, Hallingplast

Dissemination level (please select one)

SEN	Sensitive, limited under the conditions of the Grant Agreement	☐
PU	Public, fully open	☒

Nature of the deliverable (please select one)

R	Report, document	☒
DEM	Demonstrator, pilot, prototype, plan designs	☐
DEC	Websites, patents filing, press & media actions	☐
DATA	Datasets, microdata, etc.	☐
DMP	Data management plan	☐
ETHICS	Deliverables related to ethic issues	☐
SECURITY	Deliverables related to security issues	☐
OTHER	Software, technical diagram, algorithms, models, etc.	☐

Co-funded by the European Union

USES4HEAT

Disclaimer

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor CINEA can be held responsible for them.

Table of Contents

List of figures

Abbreviations and acronyms

Acronym	Description
BHE	Borehole Heat Exchanger
BTES	Borehole Thermal Energy Storage
CHP	Combined Heat and Power
CST	Concentrating Solar Thermal
DHN	District Heating Network
DHW	Domestic Hot Water
HEX	Heat Exchanger
HVAC	Heating, Ventilation and Air Conditioning
HP	Heat Pump
RES	Renewable Energy Source
STC	Solar Thermal Collectors
TES	Thermal Energy Storage

1. Introduction

This report constitutes Deliverable 4.1: Baseline Monitoring and Plan for Oslo Demo, developed as the first task in work package 4 (WP4), T4.1, led by CELSIO with the support of all partners involved in WP4.

The deliverable provides an overview of the demo site and the pre-engineering work toward its sizing and operational optimization considering not only the main waste heat source but also additional heat generation opportunities. The document presents also the main background behind the project, analyzes the current energy flows and demand profile within the district heating network while reporting on general activities undertaken during the project's first year and the contribution of the key partners.

2. Project Background

Oslo, the capital of Norway, has buildings with a significant thermal demand, particularly during the winter. This demand is primarily met through direct electric heating. Haflsund Oslo Celsio (CELSIO), the largest district heating (DH) company in Norway, covers 20% of Oslo with a district heating network (DHN) for space heating and domestic hot water (DHW).

Thermal storage in the district heating system in Oslo is an idea that was introduced over 10 years ago. A lot of excess heat from waste incineration is lost during the summer, (no heating demand), and expensive fuels needs to be used during the winter to cover the peak load for customer's demand. Over the years there has been done a lot of work to investigate the opportunity to build a storage that will store some of this heat from the summer to the winter season. In 2023 a short duration thermal storage with capacity of storing 550 MWh was finalized.

This report will summarize the baseline and monitoring plan for Oslo demo site. The background for placing a thermal storage in Furuset, North Est in the city is the development of a new part of the city. To lower the electrical demand in this part of the city, there must be new thinking. By creating a local energy market and distribution of energy, store heat from the summer to the winter, it is possible to lower the total consumption of electrical energy and again lower the investments in electrical grid into the city.

Currently, CELSIO is expanding its DH network to replace direct electric heating, aiming to provide both heating and cooling to Oslo's residents using advanced energy optimization tools. A key development project involves expanding the DHN in Furuset, a suburb in northeastern Oslo undergoing significant transformation with new residential, commercial, and office buildings designed for sustainability and innovation. CELSIO is contributing to this upgrade through a Low Temperature District Heating Network (LT-DHN) that will cover heating and domestic hot water demands.

The Furuset LT-DHN will feature an annual heat exchange of 20 GWh, a pipe length between 5-10 km, and will serve over 2,000 flats and commercial buildings with temperatures ranging from 70 C (supply) to 50 C (return). This network will connect to Oslo's High Temperature District Heating Network (HT-DHN) via a 3 km transmission pipe, leveraging excess heat from the main DHN. The HT-DHN spans 400 km and delivers approximately 200 TWh per year at temperatures between 85 C and 120 C.

Oslo’s primary DHN receives heat mainly from the Klemestrud waste incineration combined heat and power (CHP) plant (“Klemetsrud CHP – TrackMyElectricity”, “Nøkkeltall for Vårt Miljøarbeid”). This plant operates year-round due to its waste incineration process. Accordingly, the plant produces significant waste heat during the summer, except for a brief maintenance period in August. Specifically, energy demand in the summer is lower than boiler capacity and heat is then fanned off and not used. On the other hand, the city has a large energy demand in the winter, heating season. There is a need for a lot of heating capacity during the colder part of the year that must be covered by other, and more expensive heat sources, like direct use of electricity and biofuels, wood pellets, bio diesel and bio-oil, and LNG.

Within the USES4HEAT project framework, the goal is to recover some of the Klemestrud CHP plant summer waste heat using a seasonal underground thermal energy storage (UTES) system. The Oslo Furuset demo will serve as a convergence point for the existing HT-DHN and LT-DHN. CELSIO plans to install a large-scale seasonal borehole thermal energy storage (BTES) system to store excess summer heat from the Klemestrud plant and provide it to the Furuset LT-DHN during winter. This system aims to reduce thermal peak loads covered by fossil-fuels and electricity consumption by minimizing the use of electric boilers and radiators, thus promoting optimized sector coupling. The BTES, along with the connection to Oslo’s main DHN, will be the primary source of thermal energy for Furuset’s LT-DHN. Additionally, Concentrating Solar Thermal (CST) collector units will be installed to further reduce the thermal energy demand from Oslo’s main DHN and demonstrate the BTES’s ability to integrate various heat sources, particularly renewable energy sources. The connection to a LT-DHN will also enable to use the BTES in direct connection during discharge without the need for an additional heat pump.

Co-funded by
the European Union

3. The borehole thermal energy storage (BTES) site - Furuset

Furuset was initially chosen as a place to establish the BTES for several different reasons. This part of the city is part of a transition and development phase. There are several planned new buildings and activities, it is possible to engage the local community and do new thinking when it comes to the energy system and its overall management. The capacity of the local electrical grid is under pressure, due to the electrification of different sectors. For instance, there has been a wave of installing charging capacity for electrical vehicles. And previously this part of the city was not connected to Celsio’s DHN network. So, it is possible to do new thinking and implement alternative solutions when it comes to creating interconnected heat and power energy systems. In addition, there is an ongoing local project at Furuset called “Micro energy system Furuset” (Figure 1), aimed at introducing new terms and business models for moving energy locally between producers and costumer. Therefore, the local environment is well suited to include innovative solutions.

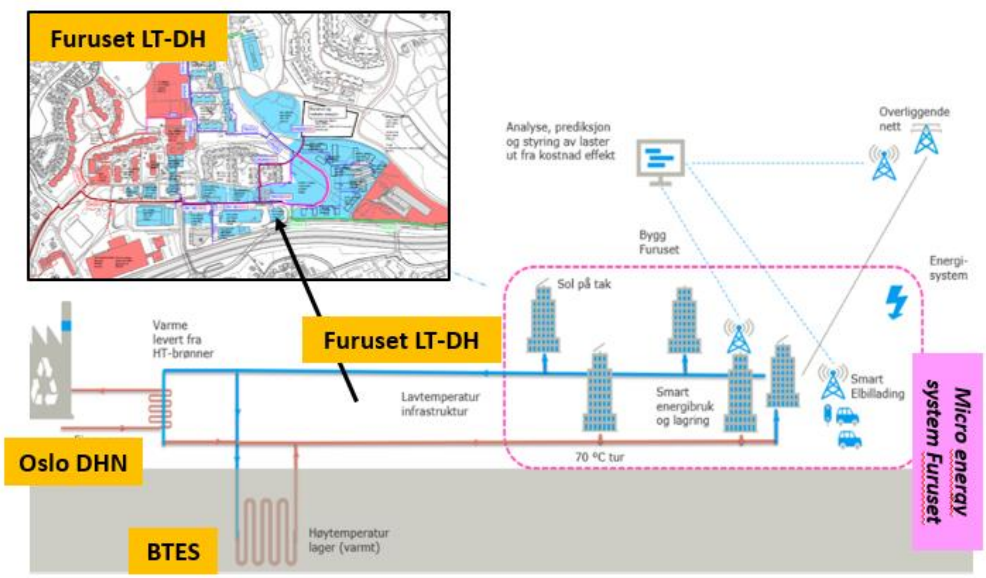

Figure 1: Micro Energy System at Furuset and integration of BTES

CELSIO is currently contributing to the upgrade of Furuset area through a Low Temperature District Heating Network (LT-DHN) that will cover heating and domestic hot water demands. The Furuset LT-DHN will feature an annual heat exchange of 20 GWh, a pipe length between 5-10 km, and will serve over 2,000 flats and commercial buildings with temperatures ranging from 70°C (supply) to 50°C (return). This network will connect to Oslo’s High Temperature District Heating Network (HT-DHN) via a 3 km transmission pipe, leveraging excess heat from the main DHN. The HT-DHN spans 400 km and delivers approximately 200 TWh per year at temperatures between 85°C and 120°C. Oslo’s primary DHN receives heat mainly from the Klemestrud waste incineration combined heat and power (CHP) plant (“Klemetsrud CHP – TrackMyElectricity”, “Nøkkeltall for Vårt Miljøarbeid”). This plant operates year-round due to its waste incineration process. Accordingly, the plant produces significant waste heat during the summer, except for a brief maintenance period in August, as shown in Figure 2. Figure 3 provides an overview of the HT-DHN and the planned connection with Furuset's LT-DHN, highlighting the Klemestrud waste incineration site and the Haraldrud DH production facility. The Haraldrud site includes a thermal energy storage (TES) system that can store up to 400 MWh at temperatures up to 120°C, acting as a buffer to reduce thermal peak demands.

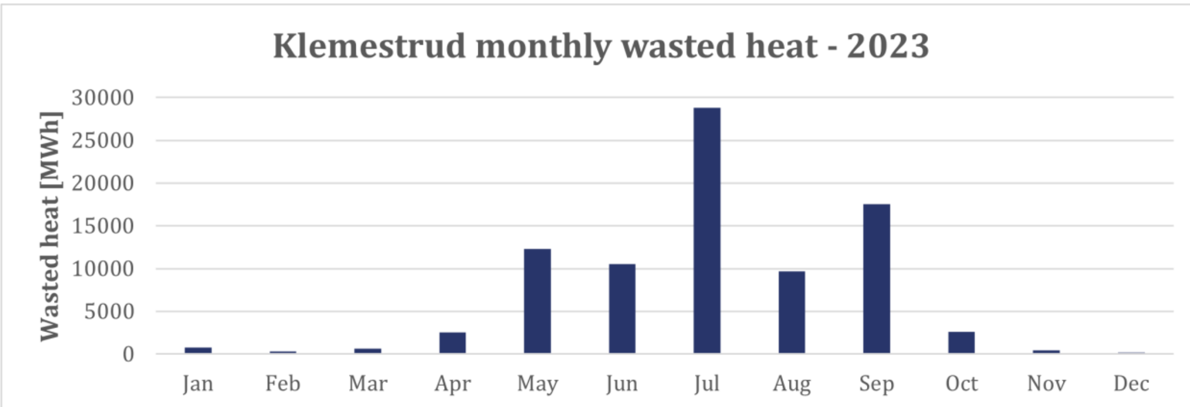

Figure 2: Klemestrud waste incineration CHP plant monthly wasted heat in 2023 (waste heat in October – April is due to isolation of the waste boilers from the grid during upscaling after mid-season maintenance stop).

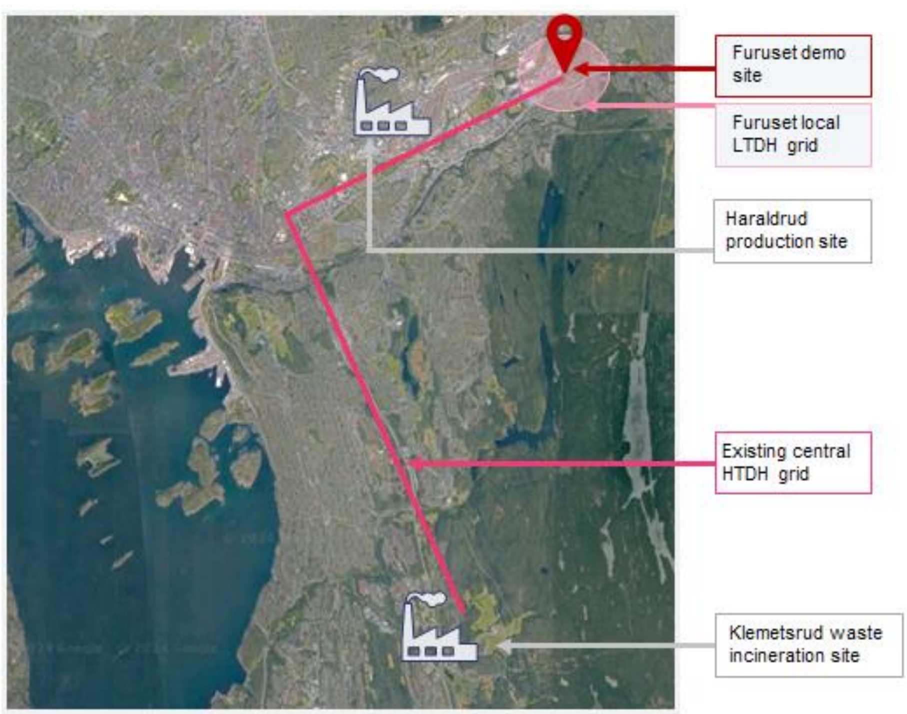

Figure 3: Overwiev map of main plants within Oslo DHN and Furuset location

Figure 4 and Figure 5 highlight the location planned for the BTES and its integration within the local LT-DHN.

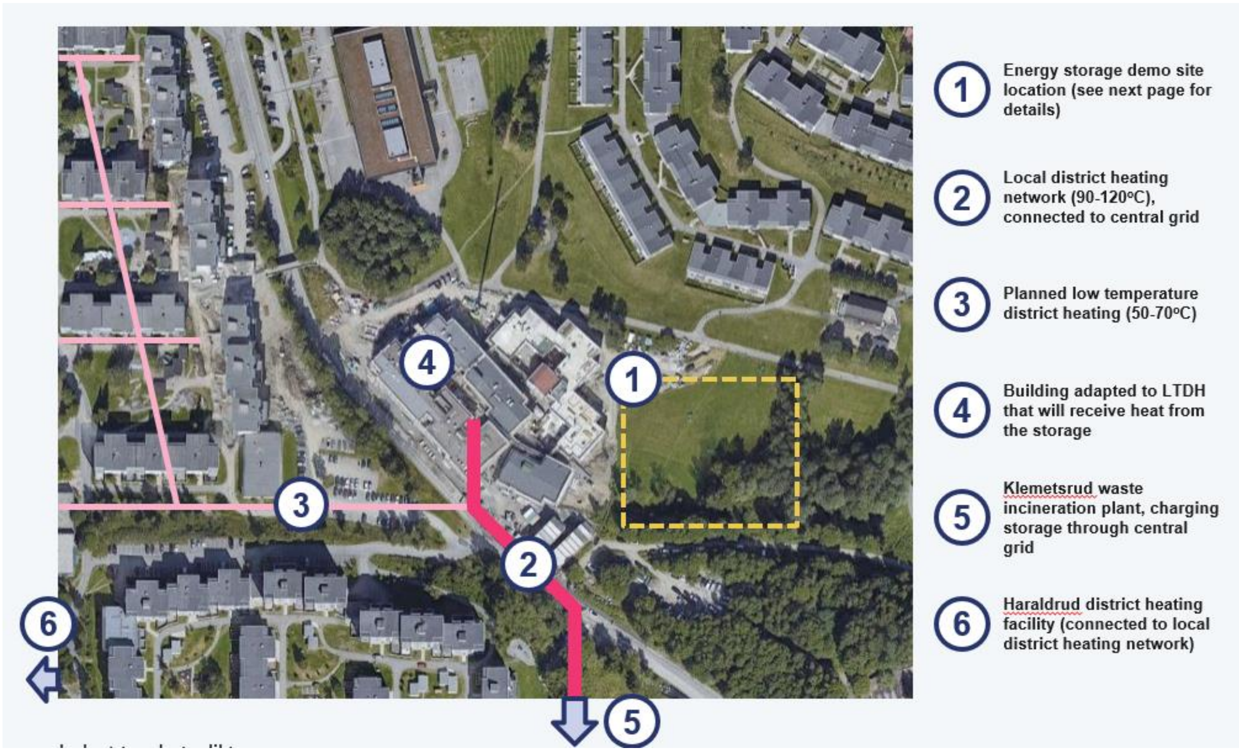

Figure 4. Location of the BTES in Furuset and limited drilling area (yellow box)

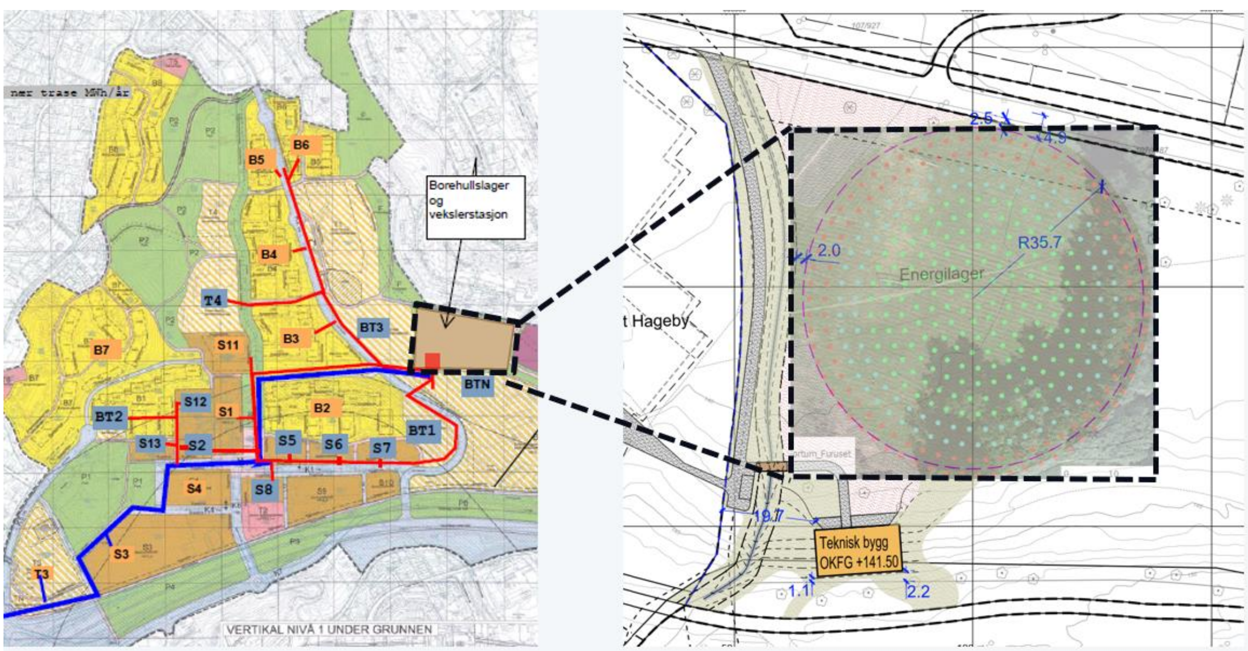

Figure 5: BTES integration within local LT-DHN

Additionally, at Furuset site the ground is suitable for storing heat and BTES installations. Between 2020 and 2022 some preliminary ground characterization work, among which hydrologeoloical investigations and Thermal Response Tests (TRTs), has been performed. The main geology is based on Granodioritic

Augen gneiss and Garnet/biotite gneiss, artesian flow was identified at depth of about 200 m, and the hydraulic transmissivity was measured between 10^{-4} and 10^{-6} m^2/s (comparatively low values). For the drilling, conventional air hammer drilling without steering control is possible with a 10° inclination towards N-NW (310° azimuth), with adjustments for specific zones.

Additionally, considering the new buildings under constructions and planned in the area they are suited and easily adaptable to lower temperature heating technologies. It should be also noted that there have also been previous test drillings done at other sites, both Klemetsrud and Haraldrud. These sites have not the right geological characteristic for storing heat and BTES implementation.

Looking at the implementation of the BTES in the Furuset area, some of the preliminary investigation (conducted by SWECO in 2023) about structural geology/ground stratigraphy of the area, mostly analyzing expected drilling deflections and permeability distribution are summarized in Figure 6.

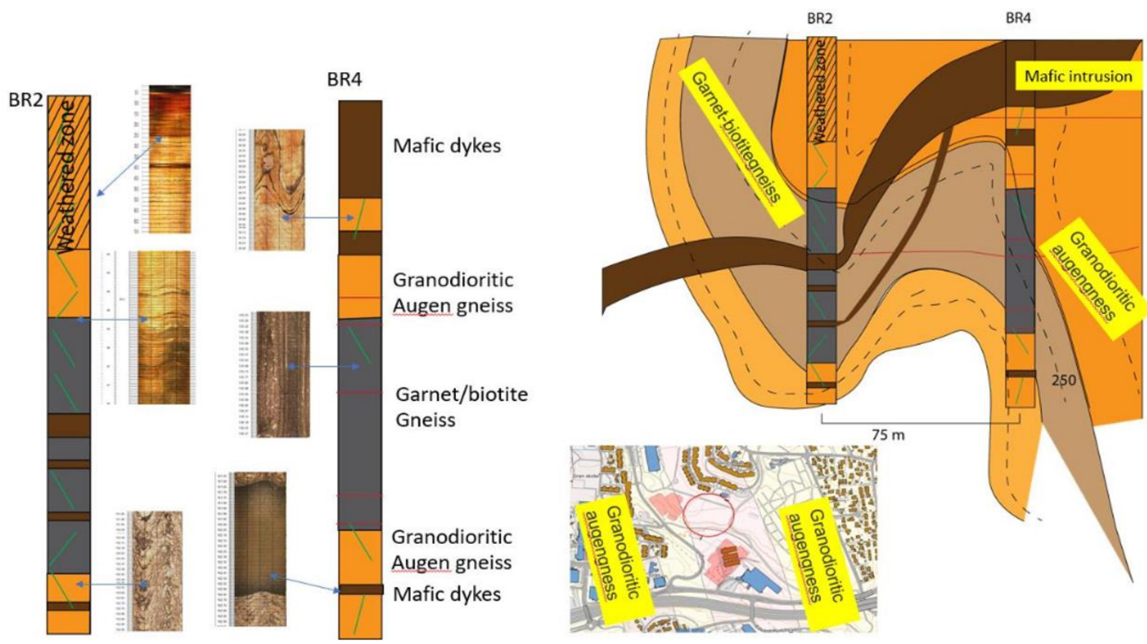

Figure 6: Preliminary Geological mapping/investigation of Furuset demosite area

At the current stage of discussion, the BTES should consist of a circular well park with 150 m depth boreholes[1] and an interface technical building. In this first phase of the project, the activities are focused on characterizing the local ground via geological mapping and in performing a sizing optimization considering costs for the installation and opportunities for CELSIO.

[1] Final depth values to be fully confirmed in the next months

3.1. BTES design optimization

As part of the main engineering of the BTES demo site the specific number of boreholes and BTES sizing has been optimized looking at cost and technical performance. More specifically, in T4.1 BD and CELSIO investigated how the number of boreholes, borehole flow rate and discharge duration affect the energy and temperature output of the HT-BTES. The number of boreholes is of particular interest since the size of the storage at this stage must be adapted to the available resource. The main aim is to find a reasonable BTES size – in terms of upfront costs – that allows to meet the project goals (specifically Main Objective 1 (MO1)).

The storage simulation was conducted using TRNSYS, employing the DST component (type 557a). The simulations spanned a period of 25 years with a resolution of 1 hour. The results obtained from the simulations, i.e., storage temperature, outgoing water temperature from the storage, heat injected and extracted were then post-processed using Python for improved clarity and analysis.

The simulations required several input data, as well as geometrical and thermo-physical parameters of the borehole field. The variable inputs for the simulation of the borehole fields are the following:

- Ambient temperature: the ambient temperature in Oslo in 2022 was used for the simulation (Open-Meteo).
- Water inlet temperature: equal to 90°C during the charging periods and 50°C during the discharging periods. These were derived considering a pinch point equal to 5 K in the heat exchanger between the storage and the district heating network.
- Mass flow rate during charging period: 0.6 kg/s per borehole
- Mass flow rate during the discharging period: 0.15-0.3-0.6 kg/s per borehole
- Discharge period of 33 or 20 weeks corresponding to the whole period when the storage is not charging and the period considering breaks between the charging and discharging, respectively.
- Number of boreholes: 25-50-70-100 boreholes

Figure 7 displays - for each year and each of the 24 scenarios - the minimum outlet temperature achieved over the year, as well as the total heat extraction. The trend is always the same: the longer the BTES is operated, the higher the temperature becomes and the more energy we are able to recover each year. However, the number of BH, the discharge duration and the discharging strategy impact the two variables in different ways. The more boreholes, the higher the temperature and the more energy we can extract. This effect is also very visible in Figure 8 which presents the total rolling energy extracted over the previous year. Furthermore, Figure 7 also shows that lower mass flow rates and shorter extraction periods lead to lower amounts of energy extracted. This effect is also visible in Figure 9, that shows the temperature evolution of the storage inlet and outlet of all scenarios for the last year of simulation.

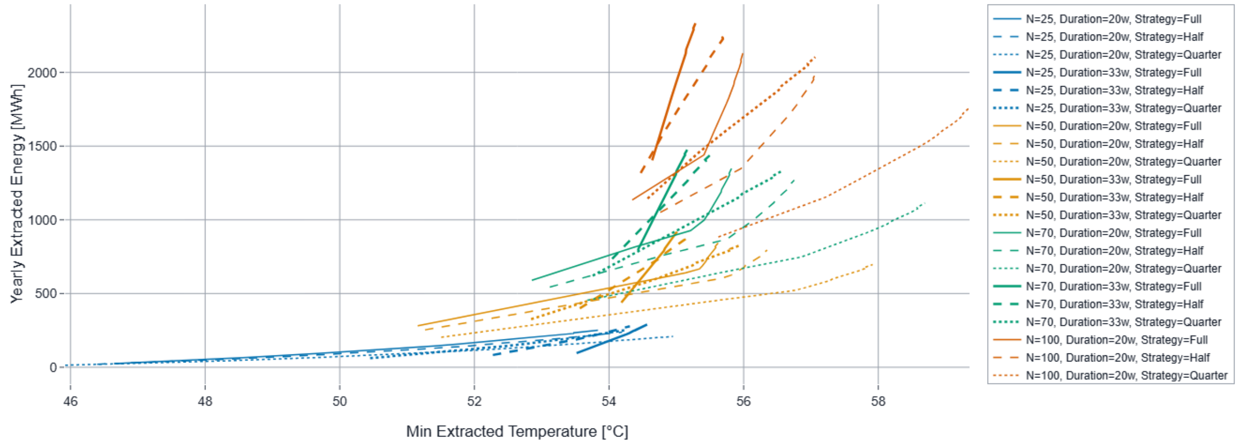

Figure 7: Minimum outlet temperature vs. extracted energy for each simulation year.

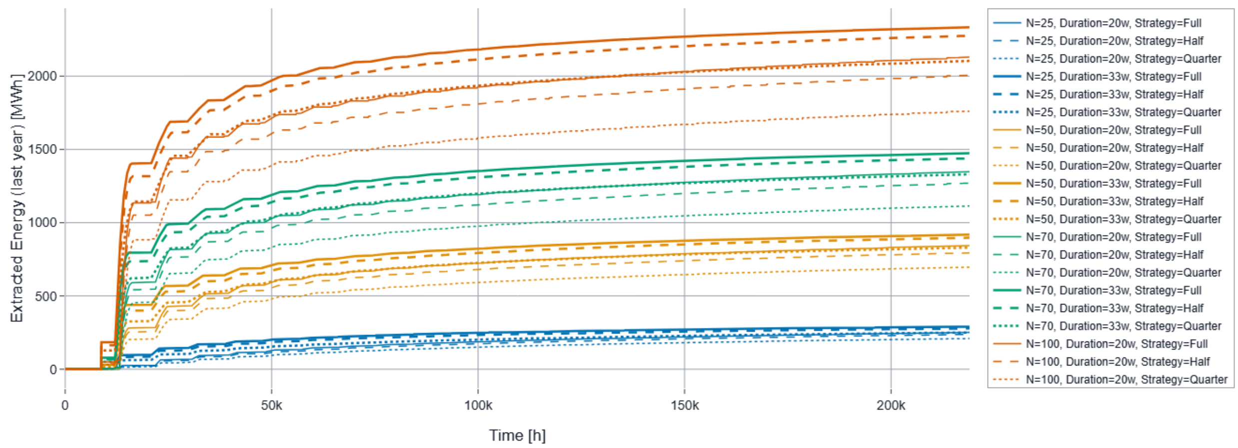

Figure 8: Total energy extracted over the previous year (between 't' and 't-1 year')

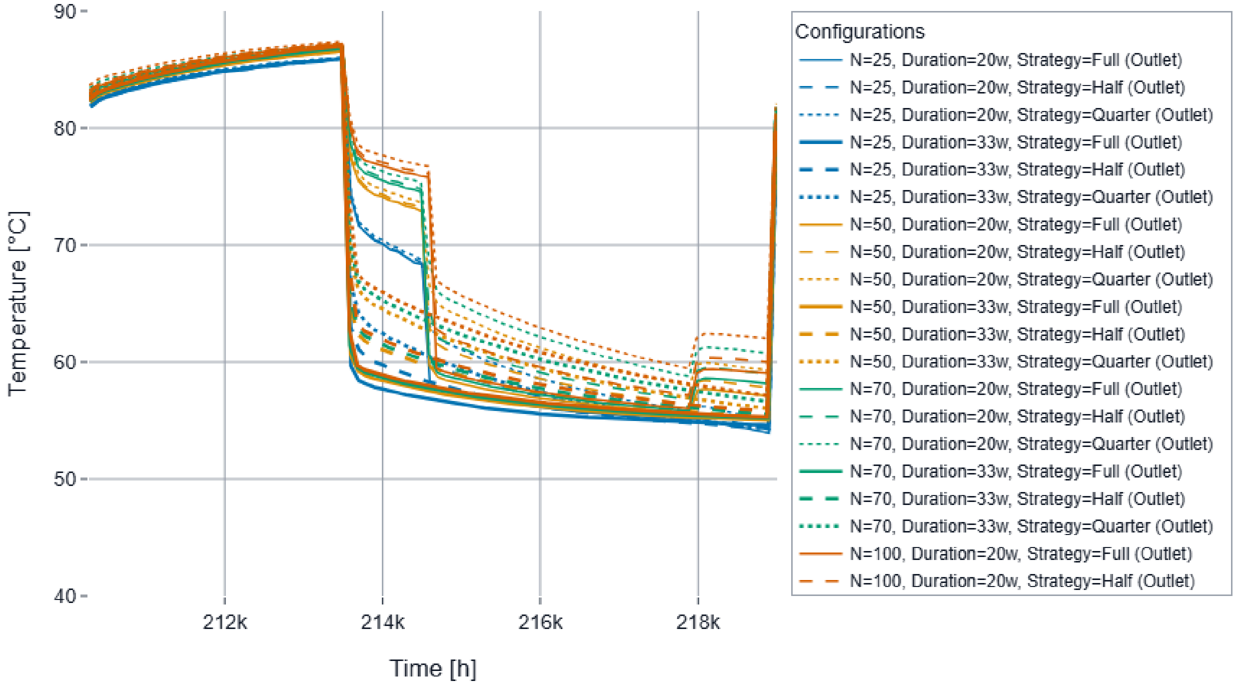

Figure 9: Temperature evolution of the storage inlet and outlet for the last year of operation (year 25)

Figure 10 displays clearly that the energy efficiency of the storage is very much dependent on the temperature and that some time is needed to reach nominal BTES efficiency. The highest average efficiency is achieved by the scenario with 100 boreholes and highest extraction period and mass flow rate and is equal to 47% after 25 years. The smallest storage studied can only achieve an efficiency of up to 17% after 25 years.

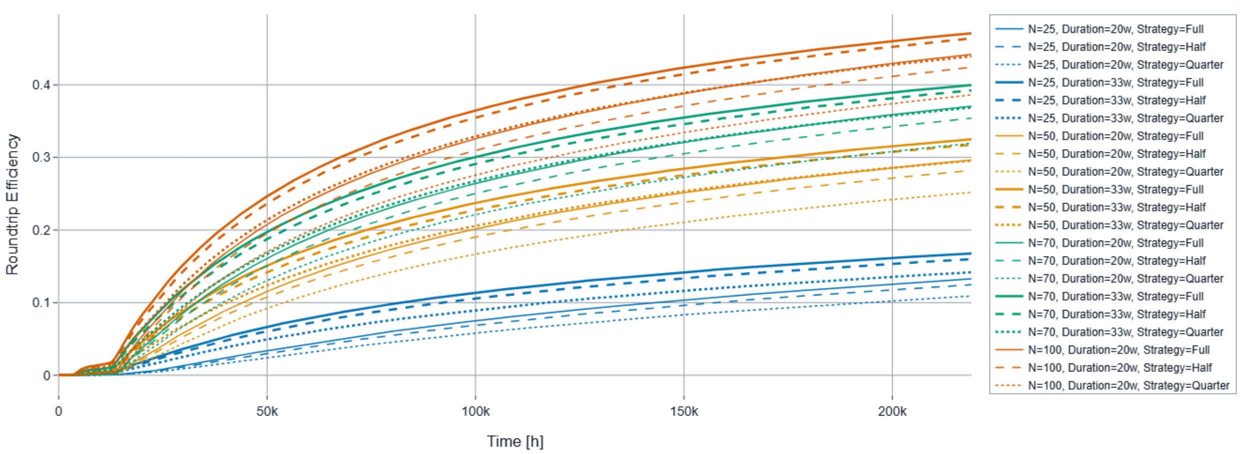

Figure 10: BTES sliding roundtrip energy efficiency over the years

Overall, for the scenarios with 25 boreholes, the outgoing temperature tends to be lower than the ingoing temperature for a significant part of the discharging period also during the last years of simulations, suggesting a limited storage capability of these configurations. Additionally, while reducing the discharging period decreases the amount of discharged energy from the storage, it also delays the point at which the discharge temperature is highest. Therefore, delaying the onset of the discharge period to coincide with the peak demand time may be a strategic approach to decreasing the load on the energy production system during the peak demand period. The storage progressively warms up and reaches saturation. The bigger the storage, the better the round-trip efficiency and lower discharge flow rate shows better performance. While the maximum and minimum discharge temperature from the boreholes does not increase significantly between year 10 and 25, the extracted energy increases by 10-20% depending on the scenario, and the recovery efficiency by 20-30%, i.e., the storage thermal performance will improve along its lifetime.The scenario with the highest amount of injected and discharged energy, i.e., scenario “33w, Full, 100BH”, allows to inject around 3.6 GWh during the last simulation year while extracting 2.1 GWh during the same period. The scenario with the lowest energy injection and extraction is scenario “N=25, 20w, Quarter” with 25 boreholes. In this scenario the injection over the last simulation year is 1.1 GWh of heat injected and 0.2 GWh extracted.

From an economic perspective the size of the BTES is a critical parameter. When the stored heat is high temperature, the size of the storage needs to be increased to ensure limited thermal losses and sufficiently high efficiencies. These analyses show that a small number, ~25 boreholes, is not a sufficient size for HT-BTES application. Additionally, the scale effect on the economic parameters should be also accounted for. For example, investment in infrastructure, above ground installation and similar are, at least partially, independent for the size of the storage and largely not linear. This means at a small high temperature storage will not be economically sustainable. A high temperature storage needs a large number of boreholes to have a round-trip efficiency that is economically sustainable, dependent also on the needs for local infrastructure investments.

In summary, longer discharging periods allow to recover higher amount of the energy stored in the underground and do not affect significantly the maximum discharge temperature. However, reducing the discharge period may be a good strategy to match the highest discharge temperature from the storage with the peak demand of the district heating network, as long as peak demand coincides with period with available power in the storage. Reducing the discharge flow rates is a valid strategy to increase the discharge temperature. However, this leads to a decreased recovery efficiency. During the first year of operation, the storage cannot be discharged at reasonable temperature levels (as expected) as the surrounding ground requires warming up. Boreholes can be also connected in series to achieve higher return temperatures from the borehole storage.

Co-funded by
the European Union

4. Key enabling technologies

4.1. High temperature collectors

One of the key investigations that need to be made is to find the right material for the collectors in the ground. Material for collectors that are able to withstand temperatures of 90-95 degrees over time is not available in the market. This material needs to be developed.

Hallingplast is a key partner within WP5, and its main role is to develop and provide the innovative pipes, named Thermex HT-Collectors, suited for the planned high temperature borehole installation. Hallingplast is performing tests of a new type of pipe, using a combination of materials in a multilayered pipe that is both flexible and can withstand high temperatures over time. The pipes are made of a layered structure with inner PPS layer which is oxygen-tight high-temperature resistant material, preventing degradation of the external layer, non-soluble, mechanically stable, providing mechanical strength and resilience. The external layer of PE-RT (commodity grade Polyethylene material) gives more flexibility, facilitates the installation and protects the PPS, the pressure bearing inner layer, during installation.

A critical aspect for the pipe is to determine the lifetime expectancy of the pipe-system under design-condition. For plastic material, this is normally done under elevated temperatures, and then the obtained values are extrapolated to give expected lifetime at service temperature. Such tests are performed according to ISO standards to find the failure-time and -modes of plastic pipes at different temperature levels, but the test-times would be far too long to give value within the end of the project. A sketch of the testing approach and typical outcomes is shown in Figure 11

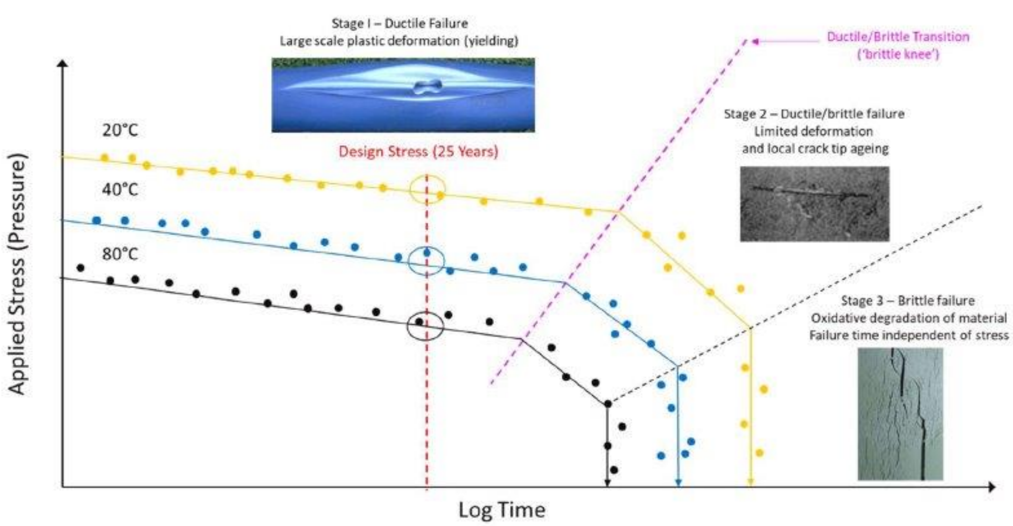

Figure 11: BTES piping testing example

Several extrusion trials have been performed so far on the pipe design with good results. The final design of the pipe and adequate extrusion parameters will be consolidated once the BTES design and testing program is finalized. As of now, Hallingplast has produced solid walls PPS-pipes in 40 x 3.7 mm and 63 x 5.8 mm for the initial pressure, material and fusion testing.

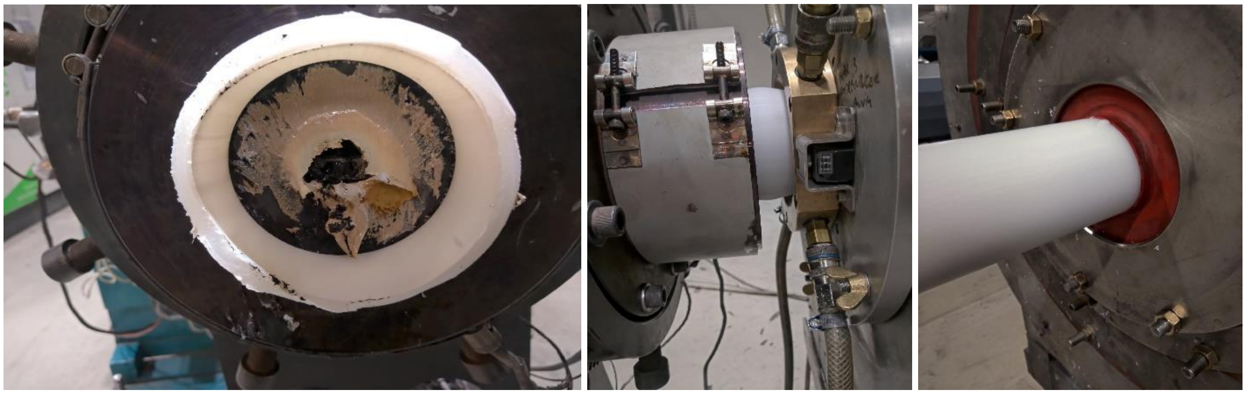

Figure 12: Picture of the multi-layered pipe extrusion process

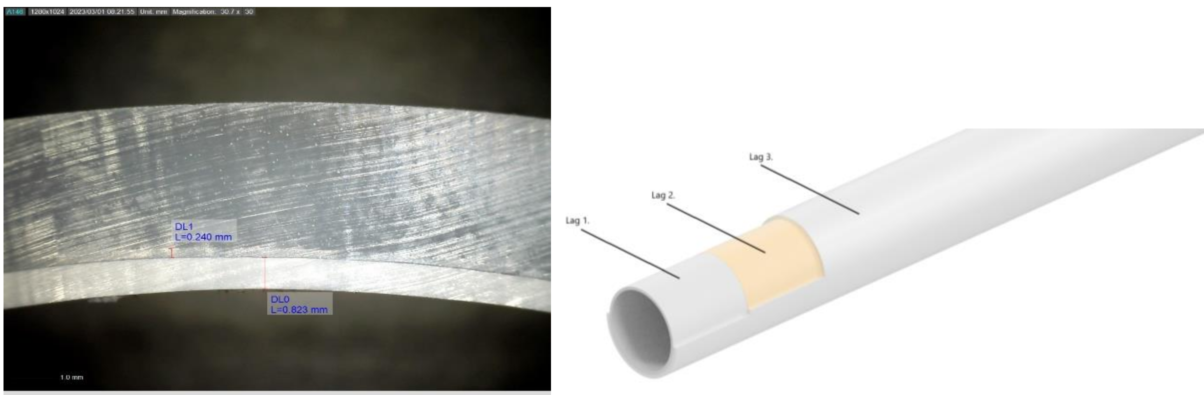

Figure 13: Multi-layer plastic pipe

To guarantee ease of installation and reduced pipe work, welding and connections are also made to obtain a system-wide solution for the full borehole heat exchangers and related above-ground pipe network. Testing includes welding the pipe with standard fusion techniques and connection with metal adaptors.

Figure 14: Testing welding connections

In cooperation with industry-leading polymer experts, Hallingplast has defined a test-program that consists of several tests that will be performed on the pipes. The test program consists of:

- Pressure testing at 3 temperature levels, 140°C, 120°C, 95°C. This test is carried out at a third party facility.
- Fuson trial
- Water absorption testing, followed by mechanical testing of material
- Falling weight impact test
- Pipe flexibility test
- Longitudinal reversion
- Resistance to weathering
- Testing of pipe with chosen fittings/pars in the form of a pipe system.

Hallingplast has already produced solid wall pipes in the high temperature resistant material to be used for pressure testing and welding trials. Initial burst-pressure testing at 140°C showed the below results indicating burst pressure higher than 25 bar, in line with the initial expectations. The long term testing with lower stress level at 3 temperatures (140°C, 120°C, 95°C) started in April 2025 with the goal of ensuring long term resistance of the chosen pipe configuration and materials selection.

Notched	Burst pressure	Description
Non-notched	28,0 bar	Ductile failure of pipe
Notched	26,5 bar	Failure in notch B
Non-notched	34,6 bar	Deformation of pipe
Notched	25,8 bar	Failure in notch D

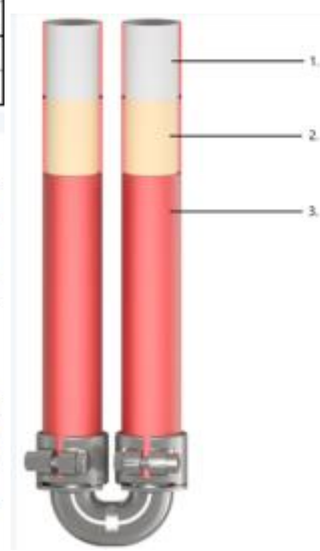

Figure 15: Pressure test – U-pipe solution (summary outcomes and photographs of samples)

Another element which needs to be resolved in the project is the fittings/ancillary parts to connect the pipes together in the bottom of the borehole to form a loop (U-bend), and in the top of the borehole to connect the pipes to the rest of the pipe system. Plastic pipes will normally have welded connections, but the high temperature resistant material has different welding properties, hence a technique suited for joining the pipes needs to be developed. Hallingplast has made trial-welds with standard fusion equipment and produced U-bends at an injection molding partner. Tests are currently ongoing with preliminary results shown in Figure 15 and Figure 16. In case of non-sufficiently reliable testing results to ensure a long lifetime of the connections with relevant safety margins, the overall plan is to use mechanical clamping fittings which are used extensively for hot-water pipes, underfloor heating pipes etc.

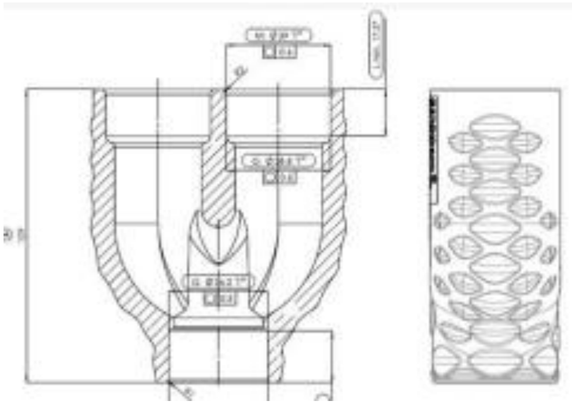

Figure 16: U-pipe solution / Some welded sections of pipes for welding test

4.2. Concentrating Solar Thermal collectors

Absolicon produces high temperature thermal solar collectors, Concentrating Solar Thermal (CST). Solar thermal collectors, in combination with thermal storage TES, will enable the overall DHN - system to store heat from different sources and be, at least partially, independent of availability of heat from waste incineration.

The initial plan consisted of installing the CST's at Furuset site, within the same area dedicated to the BTES. Two alternative designs have been investigated, Figure 17 (left) shows the STC installation above the green area were the BTES is also planned; Figure 17 (right) shows the STC installation as mounted on the rooftop of the planned technical building to serve the BTES (housing the required heat exchanger and pumps). Both installations are technically feasible from the STC standpoint, different supporting structures (such as ground screws or in-ground concrete block for the first case, or beam mounting for the second alternative) would be required (both available within the solutions offered by Absolicon). For the STC design two options have been considered: the first option is to install a 330 m^2 solar collector field on ground field (~ 132 kW$_{th}$), while the second one is to install 132 m^2 solar collectors (~ 53 kW$_{th}$), on the roof of the future technical building, which will host the necessary DHN connection units between the existing DH pipes and planned ones (both BTES and LT-DHN). The two scenarios were simulated by ABSOLICON and the main outputs in terms of solar heat production and total required footprint values are respectively 130 MWh/year and 1000 m^2 for the first option whereas 52 MWh/year and 300 m^2 for the second solution. The monthly solar heat production profiles in the two scenarios have been simulated and their results are presented in Figure 18 for the ground installation and in Figure 19 for the rooftop one.

Figure 17: Proposed layout for different solar thermal collectors' installation at Furuset site

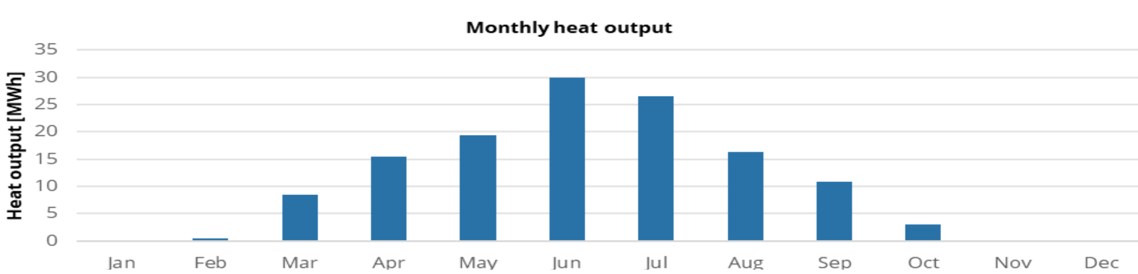

Figure 18: STC energy output scenario 1 (ground mounted)

Co-funded by the European Union

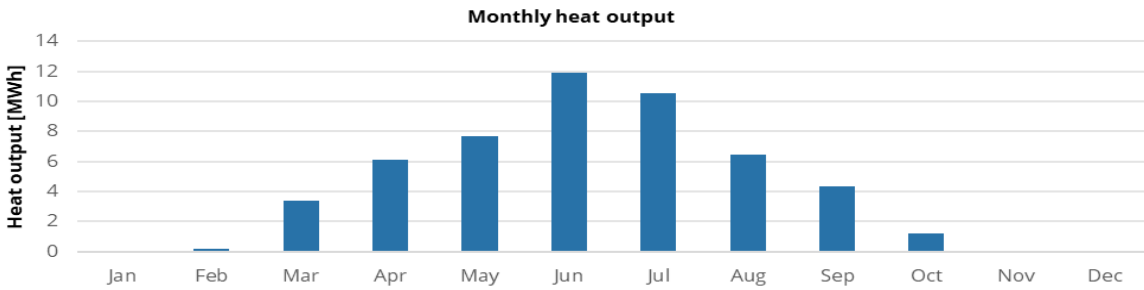

Figure 19: STC energy output scenario 2 (mounted on rooftop of technical building)

However, at a more detailed engineering level some challenges have been identified. Specifically, this area is at a low point in the terrain (with a small hill on its south side), which will lead to shading of the collectors and thus reduced energy generation. The second installation, with STC on the top of the technical building, avoids permanent use of the area above the BTES, which should be restored to the initial green field (as from current permit). However, it requires a more powerful pumping system, and it has stricter space availabilities. Additionally, as the site is not an industrial site, instead it is surrounded by residential units. The collectors have an “industrial look” and will both make some noise operating and might cause reflection of the sunlight (limited as only coming from the protective glass on top of the STCs). These aspects are likely to negatively affect the social acceptance of this installation and provoke negative repercussion on the project development and social engagement of the local community. Thus, it has been decided that this specific site is not suited for the STC installation.

An alternative layout to install CST at Furuset, close to the BTES site, is to install them at Haraldrud facilities. It is important to remember that this alternative site is still connected to the same DHN. Thus, from an overarching energy management perspective the impact of solar energy integration toward decarbonization of the DHN will be the same. This alternative has some key technical advantages with respect to the initial plan. Two different alternative designs for the STC installation at Haraldrud have been developed. As shown in Figure 20 and highlighted in more details in Figure 3, Haraldrud is the connection point between the “Grorud- grid” (main DHN in Oslo) with the rest of the DHN that also connects Klemetsrud CHP plant.

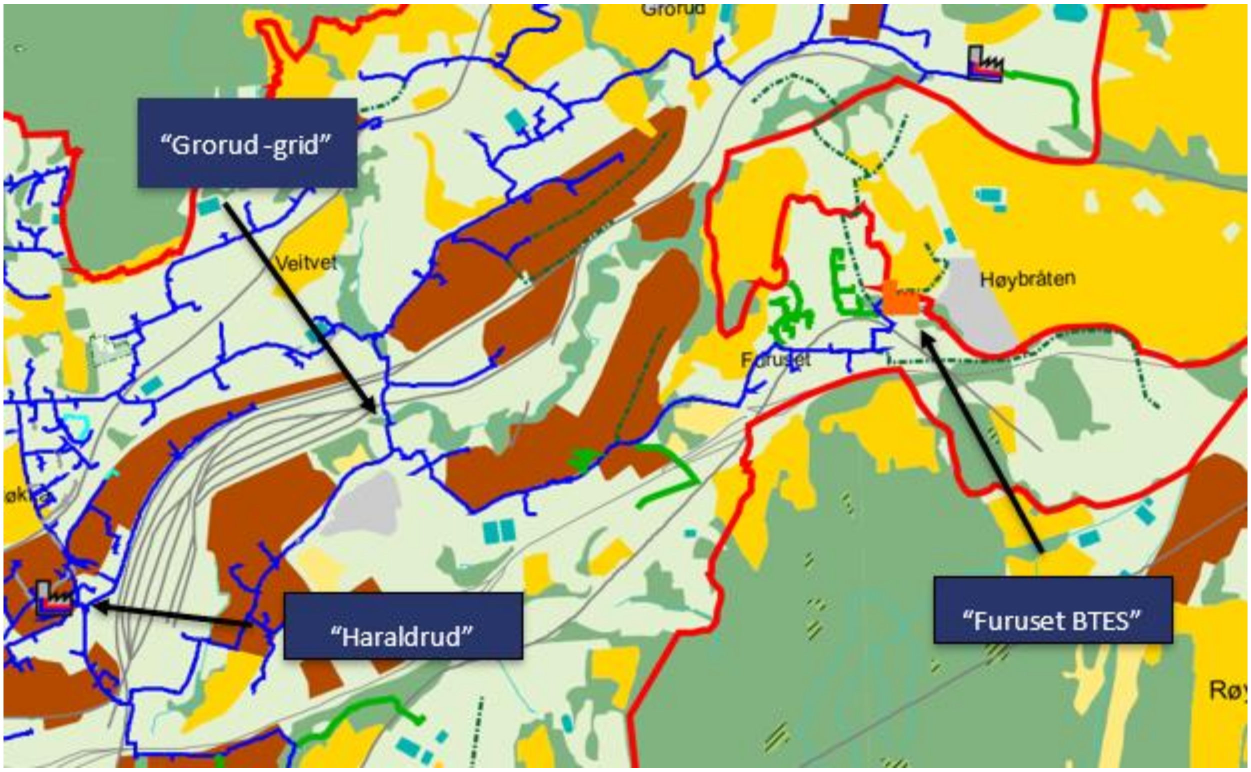

Figure 20: Overview of Grorud DHN with Haraldrud and planed location of Furuset BTES

During the summer, with low heat demand in the DHN there is no production at Haraldrud, the main DHN “Grorud-grid” receives the required heat from Klemetsrud CHP via heat exchangers located at Haraldrud, as shown in Figure 21 (left). Importantly, in 2023 a water tank based TES has been installed at Haraldrud, shown in Figure 21 (right).

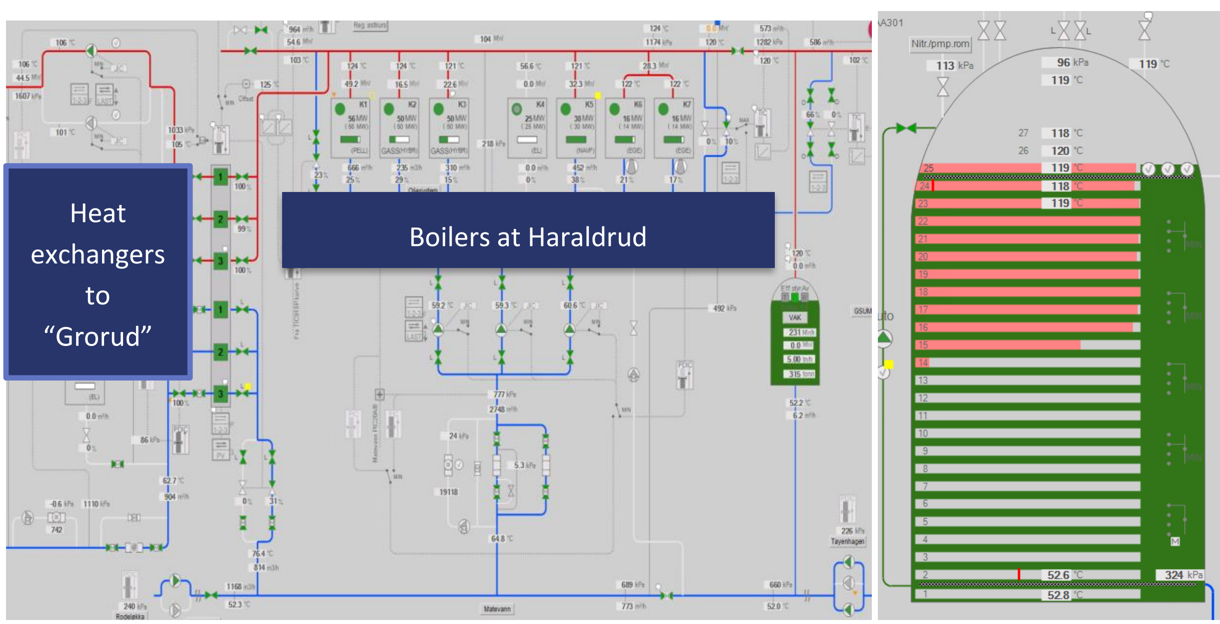

Figure 21: (left) HMI picture at Haraldrud; (right) Water TES schematic at Haraldrud (color shows temperature gradient)

The TES at Haraldrud was operational only from 2023, so there is not much history in operating the TES. A normal operating cycle is to charge during the night, when the prices are low, and discharge during morning peak demand and sometimes afternoon depending on price and heat demand. During the summer the TES is not largely used, and it is generally kept close to its maximal capacity. The summer heat demand is mainly covered by waste incineration, and there are no price differences over the day to optimize. However, some heat can be still stored during the day, instead of cooling it off, to then use the capacity during peak load over the day. The TES can be therefore available as a local buffer to accumulate heat before sending it to the seasonal BTES.

Specifically, this buffer mechanism is related to the typical operating temperatures of the DHN. To maximize storage capacity in the TES it is needed to have 120°C (Figure 21 (right)) in the top of the storage. During the summer there is no production at Haraldrud plant, the temperature in the DHN is ~100°C, or even lower to reduce heat loss, so the maximum heat storing capacity is reduced. However, the local installation of STC could enable to still have about 120°C at Haraldrud and thus maintain a higher TES capacity, whilst using the same TES as a buffer for the solar thermal energy prior to be injected in the network and stored seasonally in the BTES.

Considering the CST installation at Haraldrud site, a rooftop of the facility has been identified as a suitable location providing good surface, limited shading and good orientation. Two different collectors' field arrangements have been studied, as shown in Figure 22. The total collector area is in the range 375-400 m^2 providing a total yearly energy output between 150-160 MWh/year and a peak power up to 277 kW.

Additionally, when the CST plant is placed at Furuset site CELSIO will likely need to choose between heat from CST or waste heat since there will be simultaneously excess heat from these heat sources. This situation is not likely to occur when the CST is placed at Haraldrud. As explained before, the main reason for this is temperature and the potential buffering role of the water tank at Haraldrud. The capacity of the TES at Haraldrud is large enough to store all the energy provided by the CST. The calculated peak production capacity of 277 kW will not play a crucial role in the total production, as the total TES charging capacity exceeds 70MW.

Figure 22: CST alternative layout at Haraldrud

5. Additional considerations

5.1. Optimizing of other energy sources then excess waste heat

In the latest years, due to larger amounts of wind and solar energy in the energy mix, there are occurring times where electrical power has negative prices. CELSIO has a large portfolio of electrical boilers, and is able to profit from using these boilers to charge the TES, as a buffer, and then to store this energy in the BTES for seasonal application. With a capacity of over 200 MW electrical boilers (almost one fourth of the production capacity) there is good flexibility to leverage their production and maximize potential revenues and reduce costs. However, during the summer season, there is less capacity availability in these boilers due to summer revision (typically planned during summertime due to reduced heating requests).

Previous analysis has focused on charging the BTES only with excess heat from waste incineration, and for a period during the summer season. The result of this analysis indicates a rapid decrease in temperature when the discharge period starts. Additional heat from the DHN is then needed to deliver heat to the customers. If there are scenarios (other energy sources than waste at low cost) that also can charge the storage in the winter season, the storage is expected to show a reduced decrease in its outlet temperature. This will allow the storage to deliver more of the heat at a higher temperature, remove the dependence on additional heat and maximize the overall performance whilst potentially opening new revenue streams.

There are a few other points that should be taken into account, among which:

- The future energy mix in the DHN in Oslo will probably include less excess heat from waste incineration than in recent years. Sources like data centers will likely be a bigger part of the base heat source for the district heat.
- Excess heat from data centers comes with a cost unlike excess heat from waste incineration that is “free”. Waste incineration is a paid service.
- The price of DH - energy in Oslo is linked to the price of electricity. It is defined in the “Energy Law” in Norway that the price of DH – energy should not exceed the price of electricity.

Figure 23 shows the production profile in the DHN in Oslo in 2024 as stacked for the different production units. During the first months of the year (it was extremely cold), and shows peak production of over 700 MW. Different colors represent different fuels. Waste heat (01-REG, 02-avfall, 03-Navfall) is the bottom of the production hierarchy as it comes for free. Then the next fuel depends on demand and price which are variable in time. Typically, heat pump (04-VPA, 06-VPK) and pellet boiler (07-Pellets) are in the mid-range, and then electrical boiler are used (as characterized by lower efficiencies than heat pumps). The peak load is covered by LNG (10-LNG), bio-oil (12-bioolje) and bio-diesel (09-Biodiesel). Fossil oil (11 -olje) is practically not in use.

However, production is not always the optimal one in terms of maximizing consumption at the lowest cost. Figure 24 shows the ideal production profile in the DHN in Oslo in 2024, based on only costs. By comparing the charts it is possible to observe the difference between production and optimal production.

An optimal production profile shows that electrical energy (08-EL- light blue) could have been exploited during occurrences of negative prices (during 3 different periods during 2024). The first time was in April, when there is normally still heat demand. This shows that it is theoretically cheaper to use electricity than to burn waste in these specific hours. Similar occurrences of negative prices are expected to increase during the next years and thus can represent a key aspect in coupling of the power and heating sector and in further increasing the flexibility of the system, demanding more and more storage availability.
Waste energy was set to 0 in the model, so when the electricity price is negative the use of electrical energy is the optimal choice.

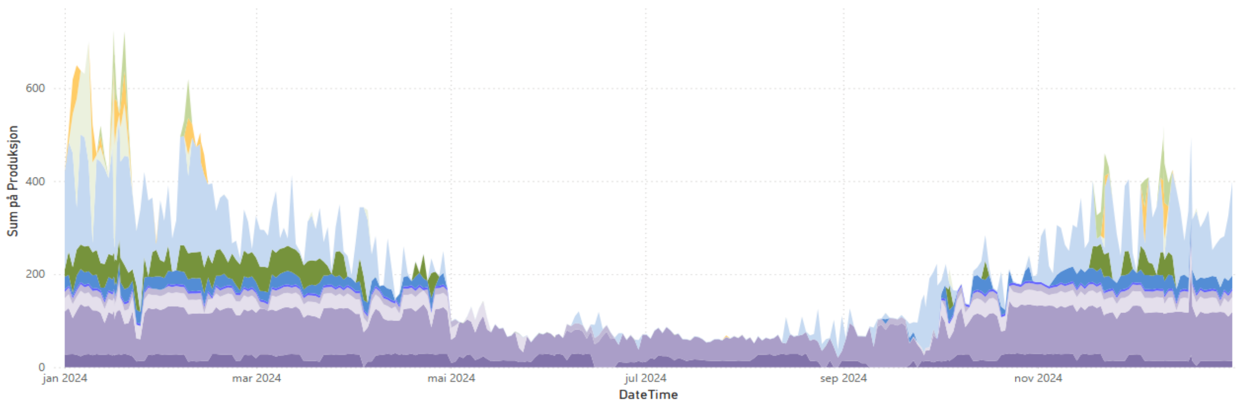

Figure 23: DH Production profile 2024

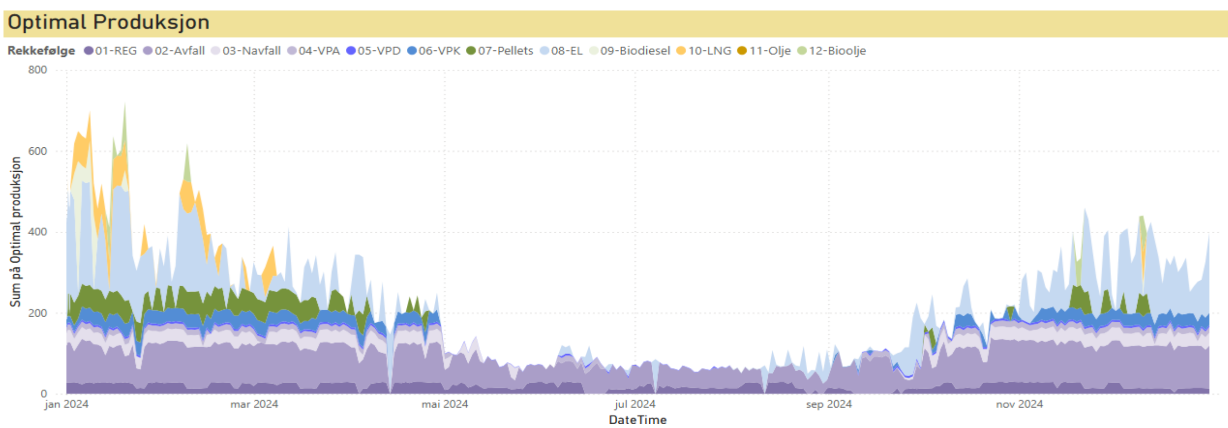

Figure 24: DH Optimal production 2024

5.2. Carbon capture and storage at Klemetsrud CHP and its impact on the DHN planning

During Q1 2025, CELSIO decided to resume the carbon capture and storage (CCS) project at Klemetsrud CHP plant in Oslo, sketched in Figure 25. CELSIO will build one of the world's first full-scale carbon capture facilities at a waste-to-energy plant. The facility is expected to be operational by the third quarter of 2029. The installation will capture the direct emissions from the Klemetsrud CHP, which alone accounts for about 20% of the city's emissions. The plant is sized to capture about 350,000 metric tonnes of CO_2 annually, with approximately 50 % resulting in permanent carbon removal from the atmosphere and 50 % being reduction in fossil fuel emissions. The captured CO_2 will be transported and permanently stored under the seabed on the Norwegian Continental Shelf.

Figure 25: Klemetsrud CCS rendering

CCS units are an energy consuming process, a large quantity of the energy to run the process needs to be added to the existing waste burning process. The waste majority of the excess heat from waste incineration in the summer will now be consumed by the carbon capture process. This will impact on the availability of free/available heat during most of the summer. Thus this will largely reduce the need for a seasonal TES within the network, instead this new CCS project might demand an increase of shorter duration TES placed within the network to provide opportunities for a flexible DHN operation by maximizing the exploitation of electricity driven units (heat pumps and electric boilers). Specifically, the flue gases from K1 and K2, two of the boilers at Klemetsrud, will go directly to the CC plant. Heat is not planned to be recovered for the DHN before the CC process to ensure that the required temperatures are available for the CC process steps. In the current configuration, the temperature of the flue gases after the CC-plant will be too low for the requirement of the DHN. Specifically, the CC-plant will produce excess heat at temperatures of about 45°C. Therefore, if we want to recover this heat for DHN operation we will need to use heat pumps to increase temperature to about 90 °C. However, this will come with an associated operational cost and will only operate when the heat is needed in the DHN.

It can be also noted that beside shorter duration TES, this CCS project might also boost the implementation of solar thermal based units within the DHN as a cheap source of heat. This might require smaller scale seasonal TES. However, such opportunities have been identified but are not yet sufficiently mature.

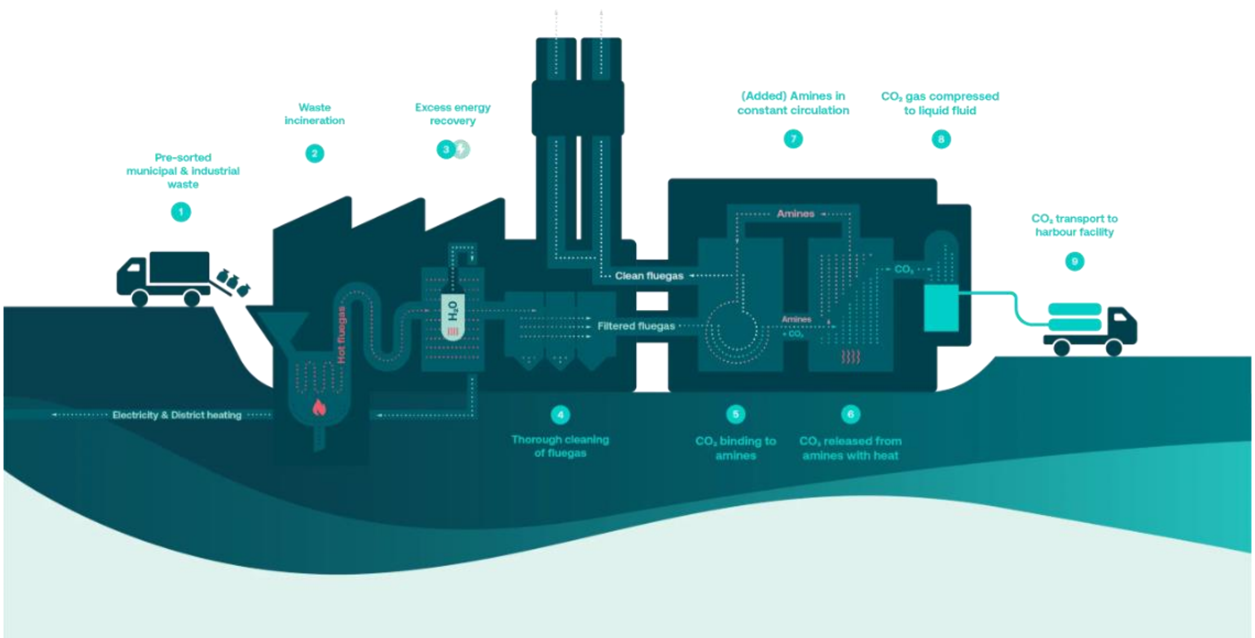

Figure 26: illustration of the main processes within the CCS plant

6. Conclusions

This report includes a summary of the work done in WP4 (and specifically in T4.1 and T4.2) within the project so far. The main conclusions from the ongoing work are as follows:

- A small, 25 -100 – borehole, high temperature storage will have low round-trip efficiency, up to 47 %. Heat loss will be elevated (particularly during the first year of operation), and such application will not be able to deliver discharge temperature high enough to deliver heat to customers without additional heat supply. Larger high temperature BTES installations are demanded to meet normal economic requirements within the industrial scale considered in CELSIO's perspective.
- Larger BTES installations come at the expense of higher overall capital expenditures. However, it is important to note that to guarantee a proper BTES operation there is a need of technical installations (piping, valves, automation, control, technical building, …). The cost of these units does not linearly scale with the BTES scale. Thus, it contributes negatively to the technoeconomic performance in the case of small BTES, but it won't have a large impact when considering larger installations.
- Hallingplast has tested different types of plastic qualities to manufacture pipes that can withstand both high temperature and pressure. Different plastic qualities combined ensure both temperature resistance and flexibility. Fittings/ancillary parts to connect the pipes together in the bottom of the borehole to form a loop (U-bend), and in the top of the borehole to connect the pipes to the rest of the pipe system are under preparation and a detailed testing plan as been developed and ongoing.
- Different CST installation opportunities have been examined. The most promising installation is within the Haraldrud site where about 400 m2 of collectors can be installed on the plant rooftop providing a total yearly energy output between 150-160 MWh/year and a peak power up to 277 kW. This installation can be also connected to the local water TES at Haraldrud contributing in maximizing its storage capacity by increasing the stored heat temperature up to 120 °C also during summer time and also acting as a buffer before longer term storage in the BTES.
- CELSIO has decided to resume the carbon capture and storage project at Klemetsrud CHP plant in Oslo. This decision has large implications over the DHN management as it will absorb the waste majority of the summer waste heat for the carbon capture processes drastically reducing the need for a seasonal TES within the DHN.

Co-funded by the European Union