TECHNICAL, ECONOMIC AND LEGAL EVALUTATION OF PIT THERMAL ENERGY STORAGE IN HIGH TEMPERATURE DISTRICT HEATING NETWORKS – TWO CASE STUDIES

Summary

This study investigates the integration of pit thermal energy storage (PTES) in high-temperature district heating systems supplied by waste-to-energy (WtE) plants in Switzerland. WtE plants offer significant unused heat potential, especially in summer, which can be utilized through seasonal thermal energy storage. Two case studies were analyzed to assess technical, economic, and legal feasibility. Results show that integration of PTES is technically feasible, even in high-temperature networks. However, temperature levels and hydraulic constraints limit the usable storage capacity. Economic feasibility remains challenging, with levelized costs of heat (LCOH) above 17–18 Rp/kWh under investigated conditions. Legal aspects are manageable but require adjustments in land-use planning and concessions. The use of high-temperature heat pumps is feasible, with increasing market availability expected. Optimized siting and system integration, especially in lower-temperature network layers, may improve performance and finally help reduce LCOH.

Keywords: Pit thermal energy storage, district heating, waste-to-energy plant, seasonal thermal energy storage

Field of application for the findings: District heating system planning and optimization, particularly for systems supplied by waste-to-energy plants

Addressed audience: District heating utilities/operators, waste-to-energy plant operators, energy system planners, researchers in thermal energy systems, policy makers

1. Introduction

Waste-to-energy (WtE) plants represent a significant yet not fully exploited source of excess heat in Switzerland. In the coming years, many existing WtE facilities will reach the end of their operational lifetime and require replacement or major refurbishment. These new or upgraded plants will be subject to stricter performance requirements, including achieving a high energetic net efficiency (ENE ≥ 0.8) as defined by current regulatory frameworks (Rytec AG, 2024).

To meet these targets, district heating (DH) systems supplied by WtE plants are expected to expand considerably. While many WtE plants already operate connected heating networks, further extensions are planned. However, direct heat supply from WtE plants is limited by their thermal output capacity. Additionally, a substantial amount of heat remains unused during summer periods when demand is low.

Seasonal thermal energy storage, particularly pit thermal energy storage (PTES), offers a promising solution to increase overall energy utilization. By storing excess heat in summer and discharging it during winter, PTES can enhance ENE and shift heat production to periods of higher demand and higher market value. However, WtE-fed networks typically operate at high temperatures (>100°C) due to large power demands and long transmission distances. This poses challenges for the integration of atmospheric PTES systems, which are limited to temperatures below 95°C.

2. Case Studies

Two case studies were conducted to evaluate the technical, economic, and legal feasibility of integrating PTES into high-temperature district heating networks. Due to confidentiality constraints, specific project details such as locations, operators, etc. cannot be disclosed.

2.1. Case Study 1

The first case involves an extended district heating network operating at supply and return temperatures of approximately 120°C and 50°C, respectively. In future, new WtE plant is planned to be connected to cover the summer load and part of the winter demand, while the remaining heat demand is supplied by a wood-fired combined heat and power (CHP) plant. The WtE plant also supplies two additional networks with higher priority, meaning only surplus capacity is available for the investigated network.

The objective of integrating PTES in this case is to increase the ENE of the WtE plant and maximize its heat contribution to the network. An existing gravel pit was identified as a potential PTES site. Due to the high network temperature level, a high-temperature heat pump (HT-HP) is required to upgrade the storage discharge temperature to the network supply level. The integration using return flow preheating was deemed ineffective, as the flow conditions at the given site would have severely limited its application, and the higher temperature would have had a negative impact on flue gas condensation in the CHP.

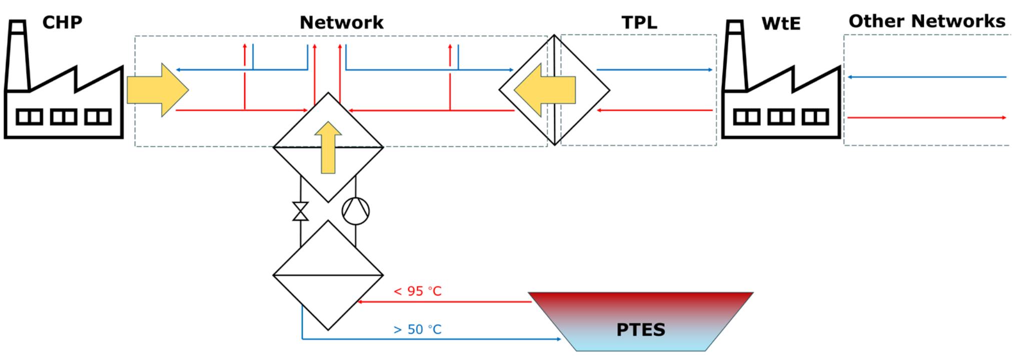

Fig. 1: Schematic system layout case study 1 with HT-HP for PTES-integration to supply heat to the DH network

2.2. Case Study 2

The second case considers a district heating network supplied by a WtE plant via a transportation line (TPL) operating at approximately 120°C/50°C. The network is expected to expand significantly over the coming decades and consists of multiple temperature layers: a high-temperature transmission level (TPL), an intermediate layer (approximately 110°C/50°C), and a lower-temperature layer (<90°C). In addition to this network, the WtE plant also serves other networks.

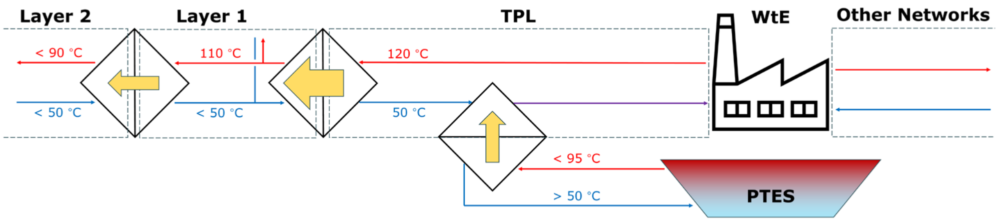

Fig. 2: Schematic system layout case study 2 with return flow PTES-integration to supply heat to the TPL

A regional site assessment along the corridor of the TPL identified potential locations for a PTES system with a target volume of approximately 500,000 m³. In this case, no heat pump is used. Instead, the PTES is integrated by preheating the return flow of the TPL. This configuration aims to provide operational flexibility at the WtE plant, enabling improved adaptation to electricity price fluctuations on both seasonal and intra-weekly timescales.

3. Methodology

Both case studies were analyzed using thermodynamic simulations implemented in Modelica. Economic evaluations were conducted using the annuity method. Capital expenditure (CAPEX) data was provided by project partners, while missing parameters were supplemented using tender data and literature sources (Nussbaumer et al., 2017; Sørensen et al., 2024; Chatzidiakos, 2020). Energy demand and operational data were supplied by the utilities involved.

For Case Study 1, the PTES size was constrained by the geometry of the existing gravel pit. Multiple scenarios were simulated, varying the available WtE capacity (depending on the expansion of other two networks) and the size of the HT-HP. Economic evaluation was based on current cost and demand data, since no significant expansion is planned. Additionally, a legal assessment was conducted by an external firm to evaluate the feasibility of converting the gravel pit, which is subject to an existing mining concession, into a PTES facility.

For Case Study 2, the PTES volume was predefined at approximately 500,000 m³ based on a preliminary assessment by the respective utility. A control strategy was implemented to operate the storage dynamically based on daily average electricity prices. Historical daily price fluctuations from 2024 were combined with projected seasonal (monthly) variations for the years 2030, 2040, and 2050 (Verband Bayrische Wirtschaft, 2024). Future heat demand was defined based on network expansion planning of the uitlity. The economic analysis included levelized cost of heat (LCOH) calculations, accounting for additional revenue from optimized electricity generation.

4. Results and Discussion

4.1. Case Study 1

The analysis showed that repurposing an existing gravel pit for PTES is technically, economically and legally feasible, but subject to several constraints. From a technical perspective, the steep embankments of the pit cannot be directly utilized, as PTES systems typically require maximum slope ratios between approximately 1:2 and 1:1.5 due to material stability and construction requirements. In contrast, the existing pit features slopes of 1:1 or steeper. The application of HT-HP is also considered technically feasible, as an increasing number of suitable products are entering the market. Although the availability of units in this temperature range is currently limited, it is expected to grow significantly in the coming decades and should not constitute a major barrier for implementation. Furthermore, the existing mining concession introduces additional legal complexity. Modifications to the concession are required, and the long-term availability of the site for alternative uses (e.g., agriculture) is restricted. From an economic perspective, the conversion leads to opportunity costs, as the original investment was based on expected revenue from the use of the site as a landfill for excavated material.

The calculated LCOH for heat supplied from the PTES exceeds 17 Rp/kWh, indicating relatively high costs. However, there is potential for optimization. It is considered more advantageous to construct a new pit specifically designed for PTES and approved as a storage project, and to extract gravel as a byproduct. This approach would allow optimization of geometry, enable a more flexible site selection where network boundary conditions are more favourable, avoid legal complications related to existing concessions, and improve economic performance by integrating gravel extraction and storage construction.

4.2. Case Study 2

The second case demonstrated general technical feasibility of PTES integration. However, hydraulic limitations of the transportation line restrict the achievable operational flexibility. As a result, the potential for optimizing electricity production at the WtE plant is constrained. The additional revenue from optimized electricity generation is estimated at approximately 200–300 kCHF per year, which is significantly below expectations. The LCOH exceeds 18 Rp/kWh, suggesting limited economic attractiveness under current assumptions. The analysis indicates that smaller storage volumes may yield better performance under the given boundary conditions.

4.3. Overall Findings

Across both cases, PTES integration in high-temperature WtE-based district heating systems is technically feasible. However, technical feasibility is not the primary limiting factor. The high temperature levels and chosen integration strategies reduce the effective usable storage capacity, as discharging below return temperature is not beneficial. Economic feasibility remains challenging, with relatively high LCOH values observed in both cases. Legal feasibility is generally given but requires adjustments to municipal land-use plans, while time-intensive inclusion in cantonal structure plans may facilitate project development.

The analyses were conducted considering PTES integration for a single network supplied by the respective WtE plant. Economic performance could be improved by integrating storage more centrally at the plant level to serve all connected networks, or by locating storage at substations supplying lower-temperature networks (<90°C), where direct heat supply is possible. Additionally, further optimization of control strategies could increase storage utilization and cycling frequency, thereby improving overall performance and economic viability.

5. Conclusions

Pit thermal energy storage represents a promising option to enhance the efficiency and flexibility of WtE-based district heating systems in Switzerland. While technical implementation is feasible, economic and legal aspects remain critical challenges. Future assessments should focus on optimized system integration, improved control strategies, strategic siting - in conjunction with future network expansions that may involve lower operation temperatures - to maximize the benefits of seasonal thermal storage in high-temperature networks.

6. References

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