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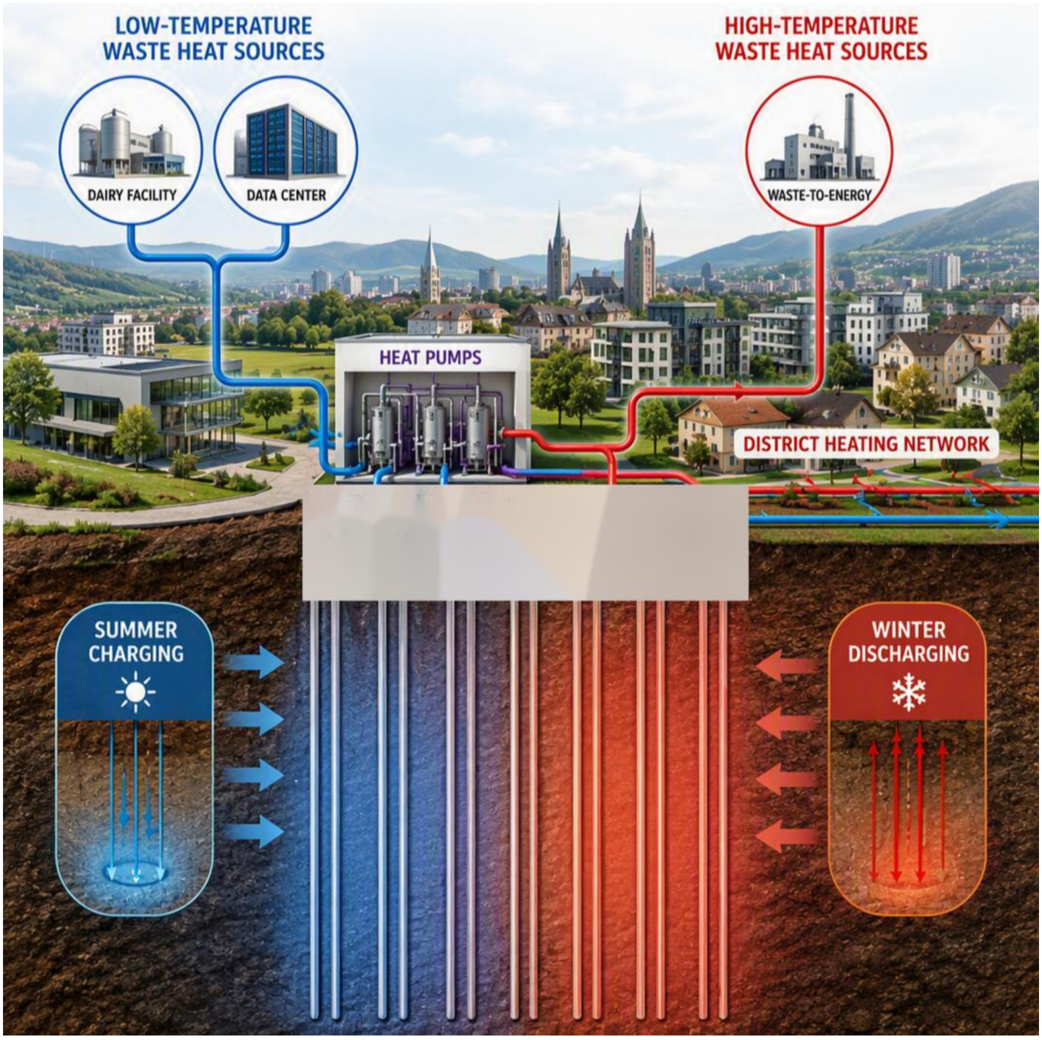

SUMMARY FOR NON-TECHNICAL AUDIENCES

INTEGRADEDH - LARGE-SCALE INTEGRATION OF LOW-GRADE SOURCES INTO DH NETWORKS THROUGH GEOTHERMAL STORAGE AND HP

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CONTENT

BACKGROUND AND RATIONALE

Decarbonizing the heating sector is a central part of the broader energy transition, and district heating can support this transition by integrating renewable and recovered heat sources in areas with concentrated heat demand. In this context, waste heat from industrial processes and urban infrastructure represents a particularly relevant resource. However, much of this heat remains underused because it is often available at temperatures below those required by existing district-heating networks, or at times of the year when heat demand is low. The InteGradeDH project addressed this challenge by examining how heat pumps and seasonal underground heat storage (in particular medium-deep borehole thermal energy storage) can help make better use of low-grade waste heat in district-heating systems.

The report assesses how low-grade waste heat can be integrated more effectively into district-heating systems through the combined use of heat pumps, seasonal thermal storage, and suitable system configurations. It focuses on technically and economically feasible integration pathways and considers not only technical performance, but also organizational and business-related conditions relevant to implementation. Two case studies, Göttingen and Bolzano, were used to connect the methodological work to real local contexts and to derive broader lessons for replication.

SCOPE OF THE PROJECT

The project examined how continuous waste-heat sources can be combined with heat pumps and borehole-based seasonal storage to overcome two common barriers to integration: the mismatch between source temperature and network requirements, and the mismatch between continuous heat availability and strongly seasonal heat demand. It considered both high-temperature waste heat, which may be integrated more directly, and low-temperature waste heat, which typically requires stronger support from heat pumps and storage.

The project also looked beyond engineering alone. In addition to the technical and techno-economic assessment, the final report addresses business models, risk exposure, and pricing implications. This is important because implementation depends not only on whether a concept works thermally, but also on whether its cost structure, ownership arrangements, and contractual setting make it practical in real district-heating systems.

FINDINGS FROM THE GÖTTINGEN CASE STUDY

The Göttingen case study focused on the north campus of Göttingen University, where waste heat from a modular data center was examined as a possible source for district-heating supply and for seasonal underground storage. The selected campus area has an annual heat demand of about 40 GWh_{th}, and the data-center source provides low-temperature waste heat at around 30 °C.

Two storage options were assessed. The first was shallow borehole thermal energy storage. The second was medium-deep borehole thermal energy storage. The shallow storage results showed a clear trade-off. Direct waste-heat recovery without seasonal storage performed better economically under the current Göttingen conditions, while adding storage could increase the amount of heat supplied and improve carbon-emission reduction. In other words, shallow storage improved heat utilization, but not enough to outweigh its additional cost under the tested conditions.

The medium-deep option led to a more restrictive conclusion. The report shows that such a concept may be technically feasible but is difficult to justify economically in Göttingen under current conditions. The main reason is the combination of relatively low source temperature, high district-heating supply temperature, and high drilling cost. The broader lesson from Göttingen is that early temperature matching is critical. If the source is relatively cool and the heating network operates at high temperatures, heat-pump-based seasonal storage becomes much harder to justify economically, even where it can be made to work technically.

FINDINGS FROM THE BOLZANO CASE STUDY

The Bolzano case study examined an existing city-level district-heating system that already integrates waste heat from a waste-to-energy plant, includes a large hot-water storage tank, and is likely to significantly expand in the next few years. This made Bolzano a useful case for studying how additional waste-heat integration and seasonal underground storage could support further decarbonization and diversification of heat supply in an established urban network. The project focused on two waste-heat summer-storage pathways: high-temperature waste heat from the municipal waste-to-energy plant and low-temperature waste heat from a dairy facility.

For the high-temperature pathway, the results were technically strong. The selected system remained thermally stable over the long-term simulation and could cover a large share of the residual winter district-heating demand. However, this technical performance came with very high investment cost, and the economic indicators remained unattractive under the adopted assumptions.

For the low-temperature pathway, the results also showed technically stable operation, but with a much smaller annual heat contribution. Similarly, the economics remained unfavorable. The report identifies drilling-related capital cost, electricity price, and financing conditions as the main factors governing viability. It also shows that lower district-heating temperatures improve thermodynamic performance, but do not by themselves alone reverse the economic conclusion. The main lesson from Bolzano is that technically stable operation is possible for both pathways, but economic viability depends strongly on local cost and financing conditions.

CROSS-CUTTING FINDINGS AND IMPLEMENTATION IMPLICATIONS

Taken together, the case studies show that heat pumps and borehole-based seasonal storage can expand the practical use of waste heat in district-heating systems by addressing two fundamental barriers: the temperature mismatch between waste-heat sources and network requirements, and the temporal mismatch between relatively continuous heat availability and strong seasonal heat demand. At the same time, the report makes clear that technical feasibility alone is not a sufficient basis for implementation.

Several broader lessons emerge from the project. First, the value of a waste-heat source depends not only on the source itself, but also on the district-heating network that is expected to receive the heat. Source temperature, network temperature, heat-pump lift, and the role of storage all matter together. Second, seasonal storage should be understood as a system-level measure rather than as a stand-alone asset. Its usefulness depends on whether it increases the annual share of usable heat in a way that justifies the additional infrastructure. Third, medium-deep borehole concepts require early screening of drilling cost and geological uncertainty, because these factors dominate the economic outcome.

The report also emphasizes that implementation depends on business and organizational arrangements. Hybrid systems that combine waste heat, heat pumps, and borehole storage involve multiple assets and often multiple actors. This creates additional needs for coordination, monitoring, contracting, and risk allocation. The project therefore supports business and tariff structures that distinguish clearly between fixed-cost recovery and variable operating costs, and that clarify the responsibilities associated with waste-heat delivery, system operation, and long-term performance. In particular, the report identifies a two-part tariff as a relevant pricing approach for systems with high fixed investment and electricity-dependent operation.

IMPLICATIONS FOR FUTURE APPLICATION

The report does not present a universal business case for integrating waste heat through heat pumps and seasonal underground storage. Instead, it provides a structured basis for identifying where such solutions are more likely to be technically sound, economically plausible, and organizationally implementable. The most promising applications are those in which waste heat is reliable, the temperature gap between the source and the network is not too large, district-heating temperatures can be reduced or are already relatively favorable, and drilling and financing risks can be kept under control.

The replication guidance in the report points toward a staged approach. Future projects should first define the system boundary and characterize the source and demand conditions. They should then assess the role of network temperature, storage need, and heat-pump integration before moving to detailed techno-economic evaluation, sensitivity analysis, and implementation design. In this way, the report supports not a single predefined solution, but a practical assessment logic for identifying viable concepts in other district-heating contexts.

OVERALL CONCLUSION

InteGradeDH shows that heat pumps and seasonal underground storage can significantly widen the practical use of low-grade and otherwise mismatched waste-heat sources in district-heating systems. The project also shows, however, that successful deployment requires a set of favorable local conditions, still within realistic ranges, but possibly difficult to occur simultaneously. Network temperatures, source characteristics, geology, drilling cost, electricity price, financing conditions, and implementation structure all shape the final outcome. For this reason, the specific feasibility ranges identified in the case studies should not be transferred directly without local reassessment.

The main contribution of the project is therefore not to claim that the proposed concept works or does not work everywhere, but to provide a structured basis for deciding where further local assessment is justified. In that sense, the report contributes both to technical understanding and to practical decision-making on future integration of waste heat and seasonal storage into district-heating systems.