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HTHP-CH – Integration of High-Temperature Heat Pumps in Swiss Industrial Processes

Zusammenfassung
Hochtemperatur-Wärmepumpen (HTWP) mit Vorlauftemperaturen über 100 °C gewinnen in der Industrie zunehmend an Bedeutung, um fossile Brennstoffe zu ersetzen. Obwohl HTWPs auf dem Markt verfügbar sind, erfolgt ihre Einführung langsam, da es Wissenslücken bei der praktischen Umsetzung gibt. Das Projekt entwickelt einen Leitfaden und ein Bewertungstool für die Integration von HTWP in der Praxis, basierend auf Fallstudien mit hoher Relevanz für die Schweizer Industrie. Der Fokus liegt auf Prozessen mit einem Energiebedarf über 100 °C auf Prozess- und Versorgungsebene und im Batch- und Dauerbetrieb. Beispiele sind Trocknung, Verdampfung, Sterilisation, etc. Geeignete HTWP-Integrationskonzepte werden entwickelt mit quantifizierten Ergebnissen in Bezug auf Effizienzgewinne, CO_2-Emissionsminderungspotenziale und Kosteneffizienz. Parallel wird das Projekt durch die Teilnahme am IEA HPT Annex 58 zu HTHPs begleitet, um die Ergebnisse und das Wissen international auszutauschen.

Résumé
Les pompes à chaleur haute température (PAC-HT) avec des températures de départ supérieures à 100 °C gagnent en importance dans l'industrie pour remplacer les combustibles fossiles. Des PAC-HT sont disponibles sur le marché, mais leur adoption est lente car il reste de nombreuses inconnues et un fossé dans la mise en œuvre pratique. Le projet développe un guide et un outil d'évaluation pour l'intégration des PAC-HT dans la pratique, basé sur des études de cas pertinentes pour l'industrie suisse. L'accent est mis sur les procédés dont la demande d'énergie est supérieure à 100 °C au niveau procédé et utilité, et en fonctionnement discontinu et continu, par ex. le séchage, l'évaporation, la stérilisation, etc. Des concepts appropriés d'intégration de PAC-HT seront développés, avec des résultats quantifiés en termes de gains d'efficacité, de potentiel de réduction des émissions de CO_2 et de rentabilité. Le projet s'accompagnera d'une participation à l'IEA HPT Annex 58 on HTHPs afin d'échanger résultats et connaissances au niveau international.

Summary
High-temperature heat pumps (HTHPs) with supply temperatures above 100 °C are becoming increasingly important in industry to replace fossil fuels. Although HTHPs are available on the market, their adoption is slow as there is still a lack of knowledge and a gap in practical implementation. This project develops a guide and an assessment tool for integrating HTHPs in practice based on highly relevant case studies for the Swiss industry. The focus is on processes with energy demand above 100 °C, in both batch and continuous operation. Examples are drying, evaporation, sterilization, etc. Suitable HTHP integration concepts will be developed with quantified results in terms of efficiency gains, CO_2 emission reduction potentials, and cost-efficiency. In parallel, the project will be accompanied by the participation in the IEA HPT Annex 58 on HTHPs to share results and knowledge with a group of international domain experts.

Motivation and Background

Switzerland is a pioneer in the development and commercialization of heat pumps. The first European heat pumps were realized in Switzerland [1]. In 2021, sales increased to an all-time high of 33'704 units (20% growth compared to 2020) [2]. Especially in the small-capacity range (i.e., single- and multi-family houses), heat pumps are an established technology for space heating and domestic hot water, with a market share of over 90% in new buildings.
In larger heating capacity ranges, especially in industry, oil and gas boilers dominate for process heat generation [3]–[5]. Therefore, replacing fossil heating systems with industrial heat pump systems is a possible scenario to reduce GHG emissions from industry.

High-temperature heat pumps (HTHP) with supply temperatures above 100 °C are becoming increasingly important in industry to replace fossil fuels [6]–[8]. The energy savings potential from a switch from fossil fuels to HTHPs in the Swiss industrial sector addressing process heat and steam below 150 °C can be roughly estimated at 2'893 GW/a, which is approximately 6.7% of the total process heat demand (Table 1).

Table 1: Estimation of the potential energy savings through the use of HTHPs in Swiss industry.

	Energy consumption	**Data source**
Swiss industry	42'972 GWh	154,7 PJ as of 2018 [9]
Process heat demand	24'107 GWh	56,1% [9] (>80 °C)
Process heat and steam below 150 °C	7'232 GWh	30% (estimate based on EU data, Heat Roadmap Europe [10])
Energy savings potential through the use of HTHP	**2'893 GWh (6.7% of process heat demand)**	40% (moderate estimate based on technical analysis and heat pump cycle proposals within SCCER EIP [11])

Compared to natural gas, which has an emission factor of 0.202 kg CO_2 per kWh of useful heat, the consumer electricity mix produced in Switzerland is 0.128 kg CO_2/kWh [12]. On this basis and with an average COP of 4.0 for an electrically-driven industrial HTHP (50 K temperature lift from the heat source to sink [6]), the generated CO_2 emissions per useful heat are about 0.032 kg CO_2/kWh, which is 6 to 7 times lower than for a gas boiler (assuming 90% efficiency).

Thus, the integration of industrial HTHPs will contribute to both energy savings and CO_2 reduction. Furthermore, the expansion of renewable energy and increased energy efficiency in industrial processes are in line with the federal government's Energy Strategy 2050 [13]. Consequently, heat pump technology supports the efforts to realize the decarbonization of industry and reduce Switzerland's net carbon emissions to net-zero by 2050 [14].

Although HTHPs are available on the market, their adoption is slow as there is still a lack of knowledge from the industrial sector and planners regarding possibilities, optimal integration, correct design, control, and dynamic behavior leading to few practical implementation examples. In general, the industrial sector lacks operating experience. There is also a need to show that HTHP technology is reliable and economically attractive. As mentioned in a white paper [15], more research is being carried out in this context on an international level, and HTHP technology is gaining higher visibility in energy systems design, particularly for process electrification.

Objectives and Framework Conditions

The primary goal of the project HTHP-CH is to develop guidelines and tools to accelerate the integration of HTHPs with supply temperatures above 100 °C in Swiss industrial applications with medium to large heat demand. At the moment, there are no such guidelines available.

The detailed objectives are:
1) Overcome the technical, economic, and non-technical barriers to HTHP integration
2) Identifying suitable concepts for HTHP integration >100 °C based on case studies
3) Characterization and clustering of typical HTHP applications
4) Development of guidelines and an evaluation tool as a decision tool to facilitate specifically the integration of HTHPs in practice
5) Evaluation of synergies and multiplication potentials with high relevance for the Swiss industry

The project also provides a basis for further add-on projects with interested industrial companies in HTHP technology. The dissemination of the project results will be made available to a broader audience of Swiss industry and the general public through publications, reports, and workshops.

In parallel, the HTHP-CH project will be accompanied by participation in the IEA HPT Annex 58 project on HTHPs to share results and knowledge with a group of international experts. Participating countries are Austria, Belgium, Canada, Denmark (Operating Agent), France, Germany, Japan, The Netherlands, Norway, and Switzerland [16]. The project duration is from 01/2021 to 12/2023. Figure 1 gives an overview of the activities.

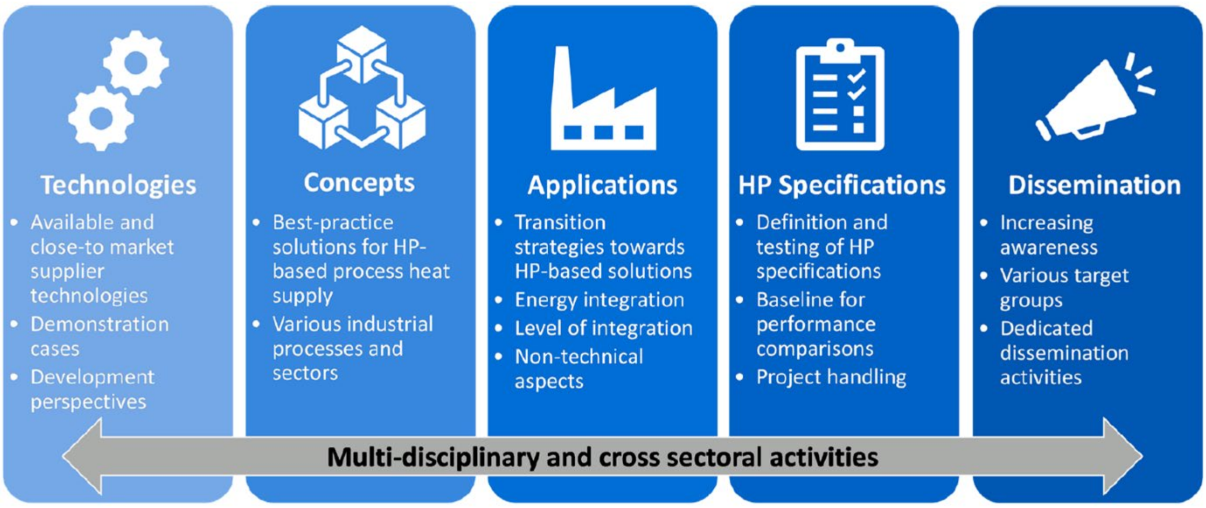

Figure 1: Overview of activities in IEA HPT Annex 58 [17].

The overall objective of Annex 58 is to provide an overview of the technological possibilities and applications of HTHPs with temperatures above 100 °C, as well as to look at process integration by developing concepts and strategies for the transition toward heat pump-based process heat supply. In addition, the intention is to improve the understanding of the technology's potential among various stakeholders, such as manufacturers, potential end-users, consultants, energy planners, and policymakers.

Organization and Cooperation

The project is a collaboration of the following research partners and combines their strengths and competencies:

- OST-IES (Institute for Energy Systems) leads the activities, develops suitable concepts for HTHP integration based on case studies, and prepares a guideline as an evaluation tool for practice.
- EPFL-IPESE (Industrial Process and Energy Systems Engineering) develops solutions (web-based tools) for the optimal integration of HTHPs based on modeling and energy systems integration.
- HEIG-VD/IGT (Energy Optimization & Pinch Analysis Competence Center) has a deep understanding of the capabilities and limitations of applying pinch analysis and has insight into the difficulties in practical implementation.
- CSD Engineers SA has close contacts with industry and heat pump manufacturers and practical experience with large heat pump projects (industrial-scale, district heating, multi-family houses, etc.).

In addition, three industrial partners in Switzerland (ELSA, Cremo SA, and Gustav Spiess AG) are actively supporting the project by supplying case studies and access to industrial process data (Table 2). Furthermore, other industrial companies (e.g., food, biotech, chemical) and heat pump suppliers are in contact with the project team showing interest in HTHPs.

Table 2: Industrial case studies for supporting the HTHP-CH project.

Industrial Partner	**ELSA Dairy**	**CREMO SA Dairy**	**Gustav Spiess AG Food (meat)**
Application/ Process Description	Several opportunities to **upgrade various heat sources** (e.g., waste heat from ammonia chillers, and from UP process) to **supply various heat sinks** (e.g, UP or UHT processes, or CIP processes).	A hot water loop operated at 105 °C to supply various processes currently being heated by a **district heating** supplied by a waste incineration plant. In case of a possible future decrease of the district heating supply temperature, a **HTHP** could be used to **upgrade the heat to 105 °C.** **HTHP integration in a milk permeate drying plant** supplied by 3 bar(g) steam and operated continuously could be another opportunity to analyze.	**Sausage cooking and smoking, steam demand at 115 °C.** Operation 12 h per day **Waste heat** is available as heat source from **ammonia refrigeration units at 40 °C to 50 °C**

ELSA (Estavayer Lait SA, member of MIGROS Industrie) is Switzerland's largest dairy site and has applications for heat treatment in the temperature range of 80 to 180 °C. CIP (cleaning in place) is a major steam-consuming side process. To save energy and water, ELSA is interested in integrating a HTHP to upgrade waste heat from the ammonia chillers (now released to the environment via cooling towers) to substitute part of the steam required for the CIP. A steam-generating heat pump should minimize the changes (i.e., avoid costly retrofit) to the process equipment at the expense of a lower COP. However, the type, integration point, heat sources, and sinks of the HTHP remain to be analyzed and confirmed.

Cremo SA (Villars-sur-Glane) manufactures dairy products and features various opportunities for integrating HTHP. The application of HTHP for adapting heat transfer from the district heating network to the internal hot water loop at 105 °C in case of a future lowering of the district heating temperature remains uncertain. The integration of a HTHP in a milk permeate drying plant (using a paddle dryer), presently consuming a large share of the 3 bar(g) steam and operated continuously, would be more readily useful to Cremo SA. The analysis of this case study shall show whether the heat sources within the drying plant are suitable to get an acceptable COP or if other heat sources of the site must be considered.

Gustav Spiess AG (Berneck, SG) is a producer of meat products and sees potential for integrating HTHP in sausage cooking processes, especially steam generation in the temperature range of 105 to 120 °C (1.5 bar). In addition, waste heat from NH_3 refrigeration units at 40 to 50 °C is available as a potential heat source.

The applied case studies will be used to evaluate and compare various HTHP integration concepts with quantified results regarding efficiency gains, CO_2 emission reduction potentials, and cost-effectiveness, bridging the gap from theory to practice.
Figure 2 shows the relation between the research partners, industry partners, the SFOE as a funding body, and further projects (i.e., IntSGHP, DeCarb-PUI, DeCarbCH).

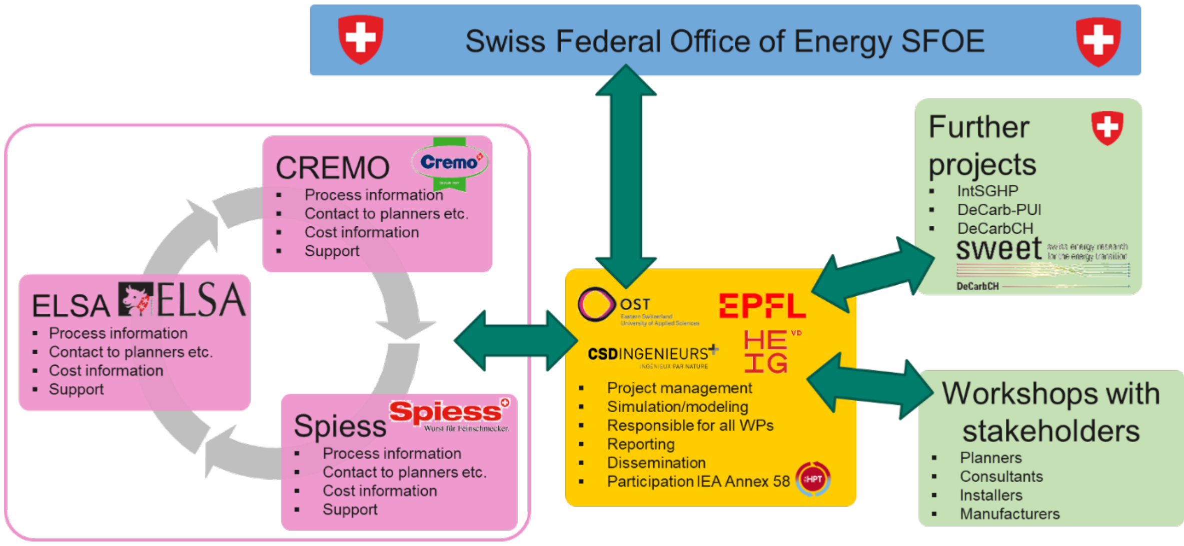

Figure 2: Relation between research partners, industry partners, SFOE, and stakeholders.

Furthermore, a support group consisting of representatives of SFOE, heat pump manufacturers, industrial companies with high-temperature process heat demand (incl. SWEET DeCarCH cooperation partners [18]), planners, installers, and associations will accompany the project from a practical point of view.
During workshops with those stakeholders' insights and feedback from the field will be gathered on technical implementation, economic, non-technical, and other barriers.

Project Description and Work Packages

The HTHP-CH project (3 years, Q4/2021 to Q1/2024) is structured in five work packages (WPs) represented in Figure 3:

- WP1: Defining a favorable framework for HTHP integration (CSD)
- WP2: Suitable concepts of HTHP integration (OST-IES)
- WP3: Solution generation for optimal HTHP integration (EPFL-IPESE)
- WP4: Guideline and evaluation tool for HTHP integration in practice (OST-IES)
- WP5: Project management and dissemination (OST-IES)

OST-IES coordinates the project as project leader, conducts substantial parts in WP2 and WP4, and coordinates all external deliverables. In addition, OST-IES provides appropriate concepts based on practice data and evaluations from case studies.
EPFL-IPESE is responsible for the central part of WP3 and develops a web-based heat pump integration tool based on superstructure optimization, but with a simplified excel-based interface. This experience also provides insights for developing the guidelines for HTHP integration in WP4.
HEIG-VD/IGT provides practical information from pinch analyses of different industrial processes and access to process data. HEIG-VD is involved in WP2, WP3, and WP4 and has insight into the difficulties from the practical side of implementation, e.g., temporal variability and information from industry profiles with high pinch temperatures.
CSD Engineers leads WP1 and provides insights and feedback from the field through workshops on technical implementation, economics, non-technical, and other barriers. This aims to understand the decision-making process and define strategies to increase HTHP implementation in industries. In addition, CSD will be involved in all WP4 tasks, including performing complete costing of some proposed concepts and contributing to elaborating the guidelines and the evaluation tool.
Together with all project partners, a generalized guideline will be developed in WP4 to quickly assess the feasibility of HTHP integration based on economic, energy, and technical criteria.

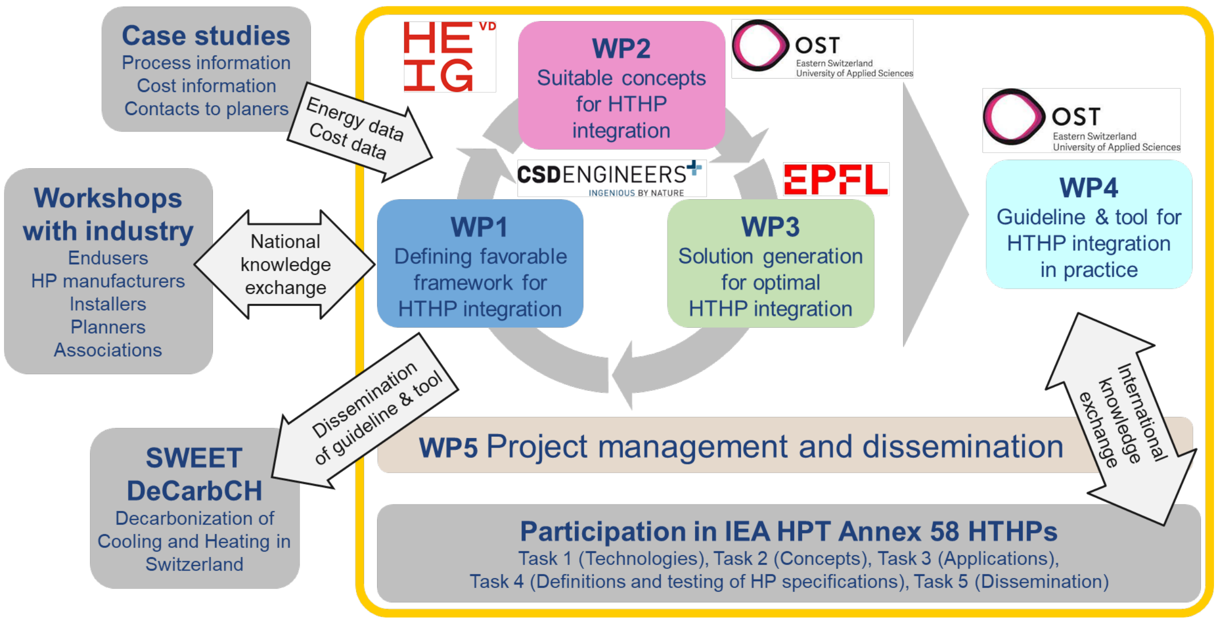

Figure 3: Structure of the HTHP-CH project and arrangement of work packages with leads and interconnection with the industrial support group, participation in IEA HPT Annex 58, and further dissemination via SWEET DeCarbCH.

The main deliverables are:

- Integration concepts of HTHPs >100 °C for the industrial Swiss case studies
- Preliminary evaluation tool for initial assessment of feasibility (go/no-go decision)
- Online tool for optimal heat pump integration in industrial processes
- Workshops involving Swiss industry with case studies and knowledge transfer
- Guideline for the implementation of HTHPs in industrial processes (market-oriented and implementation-relevant)

Dissemination of the project results will take place through national workshops with the industrial support group and further dissemination via SWEET DeCarbCH, international knowledge-sharing through participation in IEA HPT Annex 58 meetings, and other events such as HTHP Symposium, European HP Summit, or IEA conferences, and publication at national and international level. Finally, the guideline and evaluation tool is planned to be disseminated via EnergieSchweiz and national associations (e.g., FWS).

Status and Main Results

The HTHP-CH project was officially started with a kick-off meeting on December 16, 2021. In the meantime, interviews with the three industrial partners, ELSA, CREMO, and Gustav Spiess, have been conducted to clarify the industrial processes, heating demand, and temperatures and to identify possible HTHP integration points. In addition, CREMO was selected as a case study for semester student work at EPFL to identify opportunities for HTHP integration. Furthermore, the project team also addressed issues related to data sharing of sensitive energy and process data, and publication of information.

In the IEA HPT Annex 58 project framework, 8 status meetings have already been attended. In addition, a presentation on the theoretical investigation of HTHP cycles for steam generation was provided [19], and a description of the Swiss national team was posted on the Annex 58 homepage [20]. Furthermore, as part of the Annex 58 Task 1 report, which aims to provide an overview of HTHP technologies, a report on the Swiss HTHP market and perspectives has been written. The Task 1 report is in review progress.

On March 29-30, 2022, the 3rd HTHP Symposium took place in Copenhagen. It was organized by the Danish Technological Institute (DTI), SINTEF, and the Technical University of Denmark (DTU) and co-organized by the European Heat Pump Association (EHPA). The focus was on various aspects of HTHP with supply temperatures above 100 °C. OST contributed an oral presentation on the techno-economic analysis of steam-generating heat pumps in distillation processes [21] and presented a poster on the potential impact of industrial HTHPs on the European market [22]. During the symposium, the following topics were discussed in particular:

- Products from various suppliers and companies active in the HTHP market (Figure 4),
- Natural (water, ammonia, CO_2, hydrocarbons) and synthetic HFOs refrigerants with low global warming potential, as well as noble gases (e.g., helium, argon),
- Technology developments and perspectives, such as temperature-stable compressors and compressors for mechanical vapor recompression (MVR),
- Various applications in the food, chemical, and paper industries,
- Regulatory framework for the use of HTHPs, and finally,
- Numerous activities by research institutes in Norway, Denmark, Germany, Austria, Switzerland, the Netherlands, and Belgium.

All symposium presentations will be published on the website and will be a valuable source of information on the development and technology of HTHP and for researchers in similar projects and the larger SWEET DeCarbCH network.

Figure 4: Companies active in the HTHP market (Source: IEA HPT Annex 58 HTHP).

Outlook

The next step in the HTHP-CH project is to analyze available energy/process data (with time resolution) and energy costs of the three case studies in more detail and study the integration of HTHPs.

At the end of May 2022, a site visit at ELSA and CREMO is planned for the entire project team and advisory board to see the industrial processes for potential HTHP integration. In addition, the dissemination of the project results will be conducted through workshops with representatives of the Swiss industry.

For Task 2 of Annex 58, OST is taking the lead with DTI in developing various concepts for integrating HTHP technologies into hot water generation, steam generation (low/medium pressure), spray drying processes, other drying processes, evaporation processes, distillation columns, and MVR.

Acknowledgments

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