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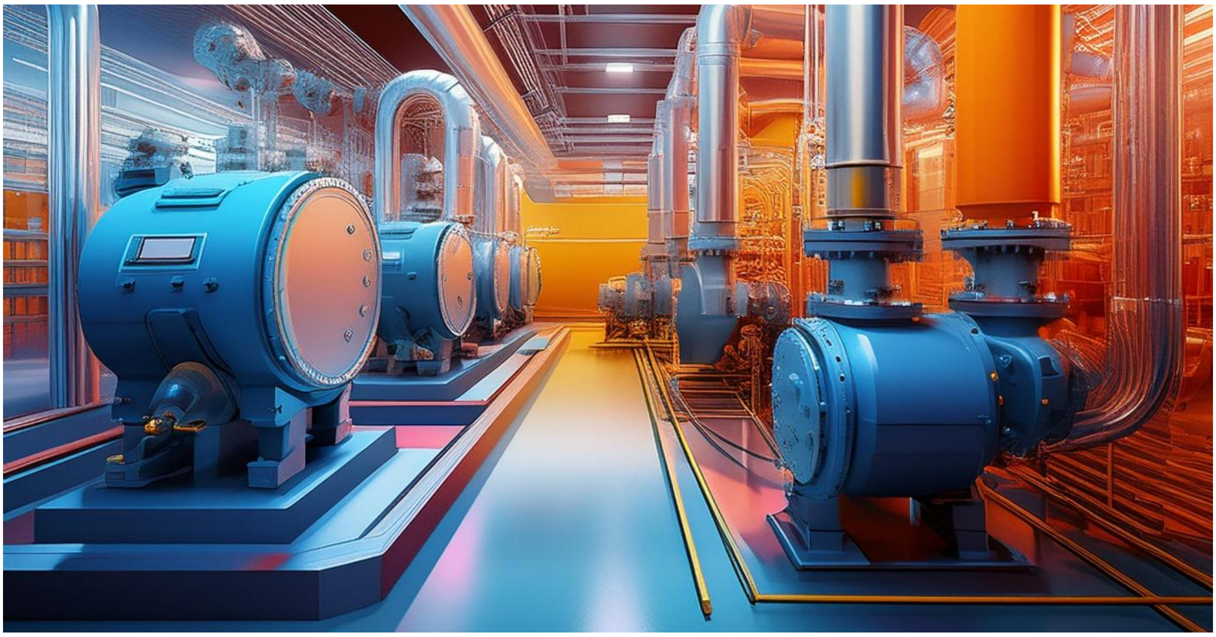
Annex 58 HTHP-CH – Integration of HTHPs in Swiss Industrial Processes

Summary Report

(Swiss contribution to the IEA HPT Annex 58 HTHP)



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Summary

Most industrial process heat is still produced from fossil fuels, but achieving Switzerland's Energy Strategy 2050 (ES2050) climate goals requires a transition to renewable energy sources. High-temperature heat pumps (HTHPs), which operate at temperatures above 100 °C, offer an efficient pathway for electrification, particularly for low- and medium-temperature process heat demands. However, adoption has been slow due to economic, technological, integration, and knowledge barriers.

The HTHP-CH project addressed these challenges by developing practical guidelines, evaluation tools, and a web-based integration platform to support optimal HTHP implementation in Swiss industry. These solutions were validated through case studies (ELSA Estavayer Lait SA, Cremo SA, Gustav Spiess AG) in processes such as drying, evaporation, and cleaning-in-place (CIP), effectively bridging the gap between theory and practice. The project also contributed to the international IEA HPT Annex 58 project.

Through these case studies, the project developed an evaluation tool and produced guidelines to facilitate the practical adoption of synergies relevant to the Swiss industry. Results were disseminated widely via webinars, publications, workshops, and international collaboration with 13 partner countries in the IEA HPT Annex 58.

The Swiss project team, comprising OST-IES, EPFL-IPESE, HEIG-VD/IGT, and CSD Engineers, focused on optimizing HTHP integration through industrial case studies, modelling, and practical guidelines. The project evaluated energy efficiency gains, CO_2 reduction potential, and economic feasibility. Close collaboration with Swiss industrial partners ensured the practical applicability of the approach, while national projects provided additional insights into local HTHP integration strategies.

A Swiss Market Report was produced, outlining the status of HTHPs in Switzerland, including ongoing research and development, market potential, realized examples, and available funding programs. The report also summarized available HTHP technologies and demonstration cases, highlighting end-user applications in various sectors, including food and beverage, wastewater treatment, electronics, chemicals, pulp and paper, ceramics, biorefinery, and pharmaceuticals. Each case study was presented with visualizations of HTHP integration concepts and technical data.

This final Summary Report summarizes the main outcomes of the HTHP-CH project and references several Appendix documents that provide comprehensive insights and additional resources to enhance understanding and application of the guidelines.

A compilation of dissemination materials like webinar presentations, workshop results, journal and conference papers, as well as lessons learned from case studies, offers valuable perspectives and facilitates knowledge transfer.

Finally, an outlook on possible next steps is provided, outlining potential future areas for further development of HTHP technology and products.

Zusammenfassung

Der Großteil der industriellen Prozesswärme wird immer noch mit fossilen Brennstoffen erzeugt. Um die Klimaziele der Energiestrategie 2050 (ES2050) zu erreichen, ist jedoch ein Übergang zu erneuerbaren Energiequellen erforderlich. Hochtemperatur-Wärmepumpen (HTWP, die bei Temperaturen über 100 °C arbeiten) bieten einen effizienten Weg zur Elektrifizierung, insbesondere für den Prozesswärmebedarf im Nieder- und Mitteltemperaturbereich. Aufgrund von wirtschaftlichen, technologischen, Integrations- und Wissensbarrieren erfolgt die Einführung jedoch nur langsam.

Im Rahmen des HTHP-CH-Projekts wurden praktische Richtlinien, Bewertungsinstrumente und eine webbasierte Integrationsplattform entwickelt, um die optimale Umsetzung von HTWP in der Schweizer Industrie zu unterstützen. Diese Lösungen wurden anhand von Fallstudien (ELSA Estavayer Lait SA, Cremo SA, Gustav Spiess AG) in Prozessen wie Trocknung, Verdampfung und Cleaning-in-Place (CIP) angewendet, wodurch die Lücke zwischen Theorie und Praxis effektiv geschlossen wurde.

Das Projekt leistete auch einen Beitrag zum internationalen IEA HPT Annex 58 Projekt. Mit Hilfe dieser Fallstudien wurde ein Bewertungsinstrument entwickelt und ein Leitfaden zur praktischen Umsetzung erstellt, wobei der Schwerpunkt, auf den für die Schweizer Industrie relevanten Synergien lag.

Die Ergebnisse wurden über Webinare, Veröffentlichungen, Workshops und die internationale Zusammenarbeit mit 13 Partnerländern im IEA HPT Annex 58 verbreitet. Das Schweizer Projektteam, bestehend aus OST-IES, EPFL-IPESE, HEIG-VD/IGT und CSD Engineers, konzentrierte sich auf die Optimierung der HTWP-Integration durch industrielle Fallstudien, Modellierung und praktische Leitlinien.

Das Projekt evaluierte Energieeffizienzgewinne, CO_2-Reduktionspotenzial und wirtschaftliche Machbarkeit. Die enge Zusammenarbeit mit Schweizer Industriepartnern stellte die praktische Anwendbarkeit sicher, während nationale Projekte zusätzliche Einblicke in lokale HTWP-Integrationsstrategien lieferten.

Es wurde ein Schweizer Marktbericht erstellt, der den Status von HTWPs in der Schweiz, einschließlich laufender Forschung und Entwicklung, Marktpotenzial, realisierter Beispiele und verfügbarer Förderprogramme, darlegt. Der Bericht fasst auch verfügbare HTWP-Technologien und Demonstrationsbeispiele zusammen und hebt Endnutzeranwendungen in Sektoren wie Lebensmittel und Getränke, Abwasserbehandlung, Elektronik, Chemie, Zellstoff und Papier, Keramik, Bioraffinerie und Pharmazeutika hervor.

Dieser Abschlussbericht fasst die wichtigsten Ergebnisse des HTHP-CH-Projekts zusammen und verweist auf mehrere Dokumente im Anhang, die umfassende Einblicke und zusätzliche Ressourcen zum besseren Verständnis und zur Anwendung der Leitlinien bieten.

Eine Zusammenstellung von Verbreitungsmaterialien wie Webinar-Präsentationen, Workshop-Ergebnissen, Zeitschriften- und Konferenzbeiträgen sowie Erfahrungen aus Fallstudien bietet wertvolle Perspektiven und erleichtert den Wissenstransfer.

Abschließend wird ein Ausblick auf mögliche nächste Schritte gegeben, in dem potenzielle zukünftige Bereiche für die weitere Entwicklung von HTWP skizziert werden.

Résumé

La majeure partie de la chaleur industrielle est encore produite à partir de combustibles fossiles, mais la réalisation des objectifs climatiques ES2050 de la Suisse nécessite une transition vers des sources d'énergie renouvelables. Les pompes à chaleur à haute température (HTHP, >100 °C) offrent une voie efficace pour l'électrification, en particulier pour les demandes de chaleur industrielle à basse et moyenne température. Cependant, en raison d'obstacles économiques, technologiques, liés à l'intégration et aux connaissances, son introduction ne progresse que lentement.

Le projet HTHP-CH a relevé ces défis en développant des lignes directrices pratiques, des outils d'évaluation et une plateforme d'intégration basée sur le web pour soutenir la mise en œuvre optimale du HTHP dans l'industrie suisse. Ces solutions ont été validées par des études de cas dans des processus tels que le séchage, l'évaporation et le nettoyage en place, comblant ainsi le fossé entre la théorie et la pratique. Le projet a également contribué au projet international IEA HPT Annex 58.

Grâce à ces études de cas, le projet a permis d'établir un outil d'évaluation et de produire des lignes directrices pour faciliter l'adoption pratique, en mettant l'accent sur les synergies pertinentes pour l'industrie suisse. Les résultats ont été largement diffusés par le biais de webinaires, de publications, d'ateliers et d'une collaboration internationale avec 13 pays partenaires de l'annexe 58 de l'AIE HPT.

L'équipe suisse du projet, composée de l'OST-IES, de l'EPFL-IPESE, de la HEIG-VD/IGT et de CSD Engineers, s'est concentrée sur l'optimisation de l'intégration des HTHP par le biais d'études de cas industriels, de modélisation et de lignes directrices pratiques. Le projet a évalué les gains d'efficacité énergétique, le potentiel de réduction des émissions de CO_2 et la faisabilité économique. Une collaboration étroite avec des partenaires industriels suisses a permis de garantir l'applicabilité pratique, tandis que des projets nationaux ont fourni des informations supplémentaires sur les stratégies locales d'intégration des HTHP.

Un rapport sur le marché suisse a été produit, décrivant l'état des HTHP en Suisse, y compris la recherche et le développement en cours, le potentiel du marché, les exemples réalisés et les programmes de financement disponibles. Le rapport résume également les technologies HTHP disponibles et les cas de démonstration, en soulignant les applications des utilisateurs finaux dans des secteurs tels que l'alimentation et les boissons, le traitement des eaux usées, l'électronique, les produits chimiques, la pulpe et le papier, la céramique, la bioraffinerie et les produits pharmaceutiques. Chaque étude de cas a été présentée avec des visualisations des concepts d'intégration HTHP et des données techniques.

Ce rapport final résume les principaux résultats du projet HTHP-CH et renvoie à plusieurs documents annexes qui fournissent des informations détaillées et des ressources supplémentaires pour améliorer la compréhension et l'application des lignes directrices.

Une compilation de documents de diffusion tels que des présentations de webinaires, des résultats d'ateliers, des articles de journaux et de conférences, ainsi que des enseignements tirés d'études de cas (ELSA Estavayer Lait SA, Cremo SA, Gustav Spiess AG), offre des perspectives précieuses et facilite le transfert de connaissances.

Enfin, une perspective sur les prochaines étapes possibles est fournie, soulignant les domaines potentiels pour le développement futur du HTHP.

Main findings («Take-Home Messages»)

- **Decarbonizing industrial heat:** HTHP-CH demonstrated that high-temperature heat pumps (HTHP, >100 °C) can efficiently replace fossil fuels in Swiss industry, supporting ES2050 climate goals and reducing CO_2 emissions.
- **Bridging theory and practice:** The project developed practical HTHP integration guidelines, evaluation tools, and a web-based integration platform, validated through industrial case studies, enabling effective implementation of HTHPs.
- **Supporting industry adoption:** By clustering applications, analysing energy and cost savings, and providing hands-on case studies, the project facilitated the practical uptake of HTHPs across multiple sectors.
- **Policy and market impact:** HTHP-CH informed Swiss energy policy and market strategies by providing a comprehensive overview of technologies, market potential, funding options, and best practices for HTHP integration

Contents

List of abbreviations

DeCarbCH:	Decarbonisation of Cooling and Heating in Switzerland
ES2050:	Energy Strategy 2050
GHG:	Greenhouse Gas
HP:	Heat Pump
HPT:	Heat Pumping Technologies
HTHP:	High-Temperature Heat Pump
IEA:	International Energy Agency
MVR:	Mechanical Vapor Recompression
OSMOSE:	OptimiSation Multi-Objectifs de Systèmes Énergétiques Intégrés (Multi-Objective Optimization of Integrated Energy Systems)
ROSMOSE:	Interface to OSMOSE based on Rmarkdown language and Quarto suite
SFOE:	Swiss Federal Office of Energy
SGHP:	Steam Generating Heat Pump
SWEET:	Swiss Energy Research for the Energy Transition

1 Introduction

1.1 Context and motivation

Today, most process heat is still generated using fossil fuels, but the transition to renewable technologies is required to meet climate targets and the objectives of ES2050 in Switzerland [1]. The industrial sector is striving to reduce CO_2 emissions and increase energy efficiency. Approximately 40% of industrial heat demand in Europe is for low or medium-temperature heat, where heat pumps can significantly reduce primary energy demand and reduce greenhouse gas (GHG) emissions [2].

Meeting the goals of ES2050 requires industrial processes to transition their heat supply from fossil resources to renewable sources. With an abundance of renewable electricity to be installed in the coming years, one approach for electrifying these industries is to implement high-temperature heat pumps (HTHPs) widely across various processes, providing both energetic and environmental benefits when electricity is supplied from renewable resources. Heat pumps currently represent the most efficient way to provide process heating.

Commercially available HTHPs with supply temperatures above 100 °C are becoming increasingly important in process heat valorisation. Although such HTHPs are on the market, their uptake is slow as there are still many unknowns regarding optimal integration, control, and dynamic behaviour.

Many companies have conducted energy analyses, e.g., pinch analysis, but there is a gap in the practical implementation of heat pump technology once the process requirements have been identified. The current applications of industrial heat pumps in Switzerland have been limited by:

- the temperatures of available technologies (<100 ºC),
- lack of appropriate methods for optimal integration,
- knowledge of the technologies, and
- other non-technological barriers.

The primary goal of this project was to develop guidelines and tools for optimal HTHP integration in industrial processes, with demonstrations using several case studies with high relevance for the Swiss industry. The focus was on selected processes with cross-sectoral parallels and potential for HTHP integration, particularly those with energy demand exceeding 100 °C, in both batch and continuous operations. Examples include processes such as drying, evaporation, sterilization, and pasteurization. The applied case studies were used to study and compare various HTHP integration concepts/strategies with quantified results regarding efficiency gains, CO_2 emission reduction potentials, and cost-effectiveness.

The developed methodology was tested and refined through actual case studies, thereby bridging the gap between theory and practice. The main deliverables were therefore:

- Practical guidelines specifically for integrating HTHPs in relevant sectors in Swiss industry,
- An evaluation tool for integrating HTHPs in industrial sites for quick pre-assessment of feasibility for heat pumps providing temperatures >100 °C,
- A web-based process integration tool leveraging optimisation techniques in a simplified way to suggest optimal heat pump/utility integration, including auxiliary guidance for user selection of working fluids and selected temperature levels, and
- Participation in the international IEA HPT Annex 58 project focusing on HTHPs.

Collaboration with IEA HPT Annex 58 was particularly leveraged in the first two aspects of these goals (technology review and application cases), providing a broad base of expertise in the field from international experts and case studies.

1.2 Project objectives

The objective of the project Annex 58 HTHP-CH was to provide an overview of the technological possibilities and applications of HTHPs with operating temperatures above 100 °C, as well as to examine process integration by developing concepts and strategies for the transition toward heat pump-based process heat supply.

Additionally, the intention was to enhance the understanding of the HTHP technology's potential among various stakeholders, including manufacturers, potential end-users, consultants, energy planners, and policymakers.

The specific objectives were:

1) To overcome the technical, economic, and non-technical barriers of HTHP integration.
2) To identify suitable concepts for HTHP integration when process temperatures are higher than 100 °C, based on industrial case studies.
3) To characterize and cluster typical HTHP applications.
4) To develop guidelines and conceive an evaluation tool used as a decision-making aid to facilitate specifically the integration of HTHPs in practice.
5) To evaluate synergies and multiplication potentials with high relevance for the Swiss industry.

The project also provided a basis for further add-on projects with industrial companies interested in HTHP technology. The project results were disseminated to a broader audience of the Swiss industry and the public through publications, reports, and workshops.

In parallel, the HTHP-CH project was accompanied by participation in the IEA HPT Annex 58 project on HTHPs, which allowed for the sharing of results and knowledge with a group of international experts. Participating countries included Austria, Belgium, Canada, Denmark (Operating Agent), France, Germany, Japan, the Netherlands, Norway, Finland, China, the USA, and Switzerland [3]. The project duration was from January 2021 to December 2023.

Literature:

[1] BFE, “Energiestrategie 2050,” 2021. https://www.bfe.admin.ch/bfe/de/home/politik/energiestrategie-2050.html

[2] R. De Boer *et al.*, “Strengthening Industrial Heat Pump Innovation, Decarbonizing Industrial Heat, White Paper,” 2020. [Online]. Available: https://www.ost.ch/fileadmin/dateiliste/3_forschung_dienstleistung/institute/ies/projekte/projekte_tes/91_sccer-eip/2020-07-10_whitepaper_ihp_-a4_small.pdf

[3] IEA HPT, “Annex 58 High-Temperature Heat Pumps,” 2021. https://heatpumpingtechnologies.org/annex58/

2 Approach, method, results and discussion

2.1 Approach and method

The **methodology** to address these challenges was implemented through a **joint project between complementary Swiss partners (OST, EPFL, HEIG-VD, and CSD Engineers)**[1], aiming to bridge the gap between theory and practice in the complex domain of HTHP implementation in the industrial sector. **Work packages** were defined to address the different facets in distinct yet interlocking phases, ensuring that the project benefited from the synergies between them.

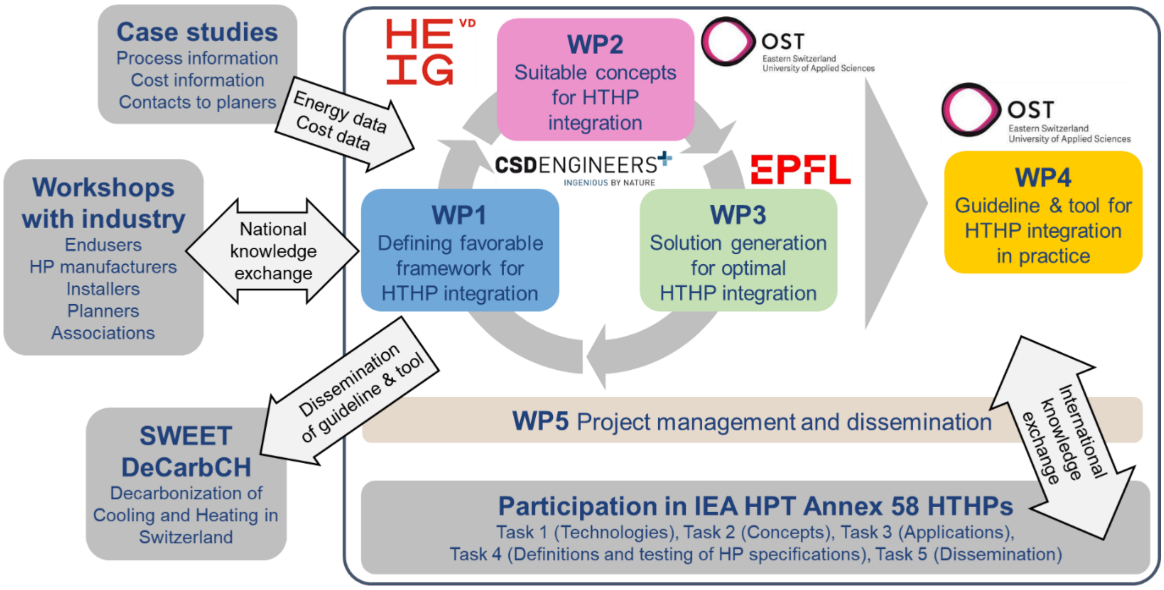

Figure 1: Arrangement of work packages with leads and interconnections with the industrial support group, the participation in the IEA HPT Annex 58 project, and the further dissemination via SWEET DeCarbCH.

Figure 1 illustrates the **arrangement of work packages**, showing the **leads** and their **interconnections** with the industrial support group, as well as their participation in the IEA HPT Annex 58 project and further dissemination via **SWEET DeCarbCH**[2].

The first work package, **WP1 (Defining a favorable framework for HTHP integration)**, aimed to develop strategies that promoted the transition to heat pump-based heat supply by establishing favorable framework conditions through workshops and analyzing realized cases. The information collected spanned a broad scope of subjects, including economics, technical and non-technical aspects, and concepts for integration.

The latter topic provided input for **WP2 (Suitable concepts of HTHP integration)** and **WP3 (Solution generation for optimal HTHP integration)**. These three work packages strongly interacted with each other. WP2 and WP3 were based on existing energy analysis (ideally pinch analysis), implying minimal updating work to bring the data to a suitable form for the project.

The results of **WP1, WP2, and WP3** on the framework, concepts, and modeling formed the basis for WP4 (Guideline and tool for HTHP integration in practice), which consisted of developing a guideline and a **preliminary HTHP Evaluation Tool** to support HTHP integration in practice. The evaluation tool (inputs: case situation, energy data, and cost; possible outputs: efficiency, list of concepts, comparison of energy efficiency, additional operational constraints, and preliminary costing) was tested and improved using suitable and available case studies.

[1] https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/03/description-of-swiss-team-for-annex-58.pdf
[2] www.sweet-decarb.ch

At the start of the project (as a go/no-go decision at the kick-off), the three proposed **industrial partners (ELSA, Cremo SA, and Gustav Spiess AG)** confirmed that the necessary data and information were available (e.g., PinCH data or equivalent) or could be collected as part of the project.

The **outcomes from WP4** condensed all the project's findings, developments, and conclusions into usable material, which was disseminated to stakeholders from Swiss industries, planners, manufacturers, integrators, and associations.

This latter point was addressed in **WP5 (Project management and dissemination)**, where the project results were also shared through IEA HPT Annex 58 and SWEET DeCarbCH. The right time alignment with the IEA HPT Annex 58 on HTHPs over 100 °C, to which the present project contributed, was highly beneficial to the study by providing valuable input to all WPs. Close coordination with other participants on Tasks 2 and 3 within IEA HPT Annex 58 prevented duplication of efforts and maximized relevant inputs and benefits from the Annex 58.

2.2 Project team

OST-IES coordinated the project as project leader, conducted substantial parts of the project in **WP2 (Suitable concepts for HTHP integration)** and **WP4 (Guideline and evaluation tool for HTHP integration in practice)**, and coordinated all external deliverables. Additionally, OST-IES provided relevant concepts based on practice data and evaluations from case studies (e.g., achievements in the field, barriers to implementation).

EPFL-IPESE was responsible for the central part in **WP3 (Solution generation for optimal HTHP integration)** and developed a web-based heat pump integration tool based on superstructure optimisation, but with a simplified Excel-based interface. This experience also provided insights for developing the guidelines for HTHP integration in **WP4**.

HEIG-VD / IGT provided practical information from pinch analyses of different industrial processes and access to process data. HEIG-VD was involved in **WP2, WP3, and WP4**, giving insight into the practical difficulties of implementation, such as temporal variability and information from industry profiles with high pinch temperatures.

CSD Engineers led **WP1 (Defining a favourable framework for HTHP integration)** and provided insights and feedback from the field through workshops on technical implementation, economics, non-technical aspects, and other barriers. This aimed to understand the decision-making process and define strategies to increase HTHP implementation in industries. CSD was involved in all **WP4** tasks, including performing complete costing of some proposed concepts and contributing to the elaboration of the guidelines as well as the evaluation tool.

Together with all project partners, a generalized guideline was developed in **WP4** to quickly assess the feasibility of HTHP integration based on economic, energy, and technical criteria.

The following industrial partners actively supported the project by supplying case studies and had already signed a Letter of Commitment (LOC):

- **ELSA** (Estavayer Lait SA, Switzerland's largest dairy site, member of MIGROS Industrie, has applications for heat treatment in the temperature range of 100 to 180 °C),
- **Cremo SA** (Villars-sur-Glane, manufacturer of dairy products, sees high potential in CIP cleaning in place, powder production and cheese manufacturing processes for electrically driven HTHPs, which have applications in the range of 100 to 200 °C, especially for 105 °C),
- **Gustav Spiess AG** (Berneck, producer of meat products, sees high potential in cooking processes, especially in the temperature range of 105 to 120 °C),

These companies committed to providing energy/process data (with time resolution) and schematics as inputs for the case studies, supplying cost data on energy at a site to derive realistic cost estimates, and participating in progress meetings and knowledge sharing.

2.3 Results and discussion

The **Swiss HTHP-CH Team** participated as representatives in the **IEA HPT Annex 58** project. In **WP1**, a **Swiss Market Report** (**Appendix 1**) was developed, outlining the status of HTHP technologies in Switzerland, including ongoing research, development, market potential, realized examples, and funding programs. The report also summarizes commercially available **HTHP Technologies in the form of Factsheets** (**Appendix 2**) and **Demonstration Cases** (**Appendix 3**) that were presented at the **HTHP Workshop** with Swiss industrial companies on 24 March 2023 in Ittigen, Bern (**Appendix 8**).

The Swiss HTHP-CH Team summarized **12 demonstration cases** focused on end-user applications and experiences, including **food and beverage, wastewater, electronics, chemicals, pulp and paper, ceramic, biorefinery, and pharmaceutical**. Each demonstration case study was summarized, accompanied by further visualizations of the HTHP integration concepts and technical data (**Appendix 3**).

To the authors' best knowledge (as of 2024), only two **Swiss manufacturers, FRIOTHERM AG and MAN Energy Solutions AG (now Everllence), produce HTHP technology above 100 °C**. These companies focus on large-scale, customized heat pumps with heating capacities in the MW range. The large-scale HTHPs from Everllence and FRIOTHERM AG can reach up to 150 °C and 120 °C, respectively, with high efficiency.

Realized heat pump installations with over 90 °C supply temperature in Switzerland (as of 2024) include:

- **Mountain Cheese Factory (Gais, Appenzell)** with a 520-kW heat pump using R1234ze(E) and an economizer cycle providing process heat up to 92 °C,
- **GVS Landi (Schaffhausen)** with a 63-kW heat pump using R1234ze(E) supplying heating (80 to 95 °C) and cooling (48 kW) demands with a COP of 4.2,
- **Slaughterhouse (Zurich)** with three CO_2 heat pumps supplying 90 °C hot water for slaughtering and cleaning-in-place (CIP),
- **New Roots AG (Oberdiessbach)** with a CO_2-HTHP producing process water up to 105 °C for producing vegan alternatives to cheese and dairy products, and
- **Empa NEST (Dübendorf)** with a CO_2-HTHP prototype that provides heat up to 119°C for a wellness sauna.

Besides closed-cycle HTHPs, **MVR (Mechanical Vapor Recompression**) is a success story in Switzerland (**Appendix 1**). There are several operational examples, mainly applied to the food industry, such as Saline de Bex (brine concentration for salt production), Cremo (milk concentration), Nestlé (coffee extract concentration), or Ramseier (fruit juice concentration).

Still, the **Swiss market for HTHPs is in an early stage**, with significant potential for decarbonization in industrial sectors such as food/beverage, chemicals, and paper. The **estimated market potential** ranges from **723 to 3,616 GWh/year**, representing **3% to 15% of Swiss industrial process heat demand**. Moreover, considering a total heating capacity of 145 to 723 MW may entail investments of between **69 to 542 million CHF**. Assuming an average heating capacity per HTHP unit of 1 MW, this results in a need for approximately **145 to 723 HTHP units (Appendix 1)**.

Several **Swiss and European funding programs** support HTHP research and adoption (**Appendix 1**). National and international research projects are focused on improving the efficiency and integration of industrial HTHPs. In particular, the **SWEET DeCarbCH project** is investigating industrial-scale HTHP applications. These programs drive HTHP innovation in industrial processes, buildings, and sustainability strategies while addressing technical and economic challenges.

Currently, there is a **lack of knowledge about integrating HTHP into industrial processes**. Tailored HTHP designs are needed, and planners and integrators are challenged to find optimal integration points. A literature review on **HTHP integration concepts** is provided (**Appendix 4**). Schematics and literature references describe examples of HTHP integration concept studies, including concepts for distillation processes, drying, steam, dairy, food, paper, and district heating, among others.

The **Integration Guidelines Report** (**Appendix 5**), created in **WP4**, is a dissemination document designed to raise awareness of current HTHP technology, comprising technical, financial, and socio-economic aspects from a global perspective. The guidelines were developed and consolidated during the case study work (**WP1, WP2, and WP3**). Their application is envisaged in future practical examples.

The guidelines document targets managers, technicians, planners, and engineers, providing essential insights into HTHP technologies, demonstration cases, and integration concepts, along with checklists for implementation and references for further reading.

- **PART A** is an **Executive Summary** providing a general overview, including an introduction to HTHP technology, case studies, benefits for decarbonization, selection criteria, and an introduction to Pinch Analysis for process integration assessment.
- **PART B** is a detailed **Technical Report** for professionals, covering Pinch Analysis applications, data collection, technical considerations, financial aspects (e.g., business models, costs, energy prices, funding and subsidies), socio-economic factors, and a web-based HTHP integration tool (ROSMOSE), demonstrated through case studies.

In addition, **Appendix 5 (Chapter 5 in PART B, Web-based Tool for HTHP Integration)** describes the **web-based HTHP integration tool ROSMOSE**, developed by EPFL, an interface to the **OSMOSE engine** based on the Rmarkdown language and the Rstudio Quarto suite. OSMOSE stands for Multi-Objective Optimization of Integrated Energy Systems, and it has been conceived as a flexible, open-source solution for modeling and analyzing industrial energy systems. The **ROSMOSE tool** features a **user-friendly, web-based frontend** that simplifies data input, reporting, and graphical representation while delegating the optimization tasks to the OSMOSE backend.

The **web-based tool** automates sensitivity analyses, Pinch Analyses, and the calculation of thermodynamic, economic, and environmental indicators. It supports multiple output formats, including PDFs and interactive HTML reports. In this way, pinch methodology experts can use ROSMOSE to screen the adequate heat pump temperature levels and choose the most suitable fluids to operate one or more HTHPs. The tool was exemplified in **two case studies (Appendix 5, Chapter 5.3 in PART B)**: a whey and ultrafiltration retentate drying unit (Tixotherm™ process) and a Cleaning-in-Place (CIP) unit.

Currently, the ROSMOSE environment operates within a virtual environment hosted by EPFL, where installation, maintenance, and management of confidential data are handled. **Appendix 5 (Chapter 5 in PART B)** outlines the procedure for accessing the virtual machines at EPFL and installing ROSMOSE. Future development will focus on enabling public access to the web-based integration tool (e.g., a Pinch Small project with the Swiss Federal Office of Energy).

The **Case Studies Report (Appendix 6)**, elaborated in **WP2 and WP3**, presents the insights gained from the practical integration of HTHPs in Swiss industries, which were disseminated through various events, such as workshops, webinars, conference presentations, publications, and talks (Chapter 5). The case studies formed an essential basis for preparing the **Integration Guidelines** (**Appendix 5**).

- In the **Cremo case study (Appendix 6, Chapter 1)**, a technically feasible and environmentally beneficial MVR heat pump solution was developed, achieving an 87.3% reduction in annual CO_2 emissions for a paddle dryer steam supply with mature technology and efficient integration near the production unit. However, challenges such as the absence of a pre-existing pinch analysis, low steam flow rates limiting the development of suitable market-ready products, and a lack of profitability hindered implementation. Additional issues included semi-continuous operation, difficult access for installation, and uncertain eligibility for subsidies.
- The **Gustav Spiess case study (Appendix 6, Chapter 2)** showed sufficient waste heat at about 45 °C from ammonia chillers as a potential heat source for a 200-kW SGHP supplying low-pressure steam at 1.5 bar(a). This could substantially reduce energy costs and CO_2 emissions compared to gas heating, with strong potential for wider use in the Swiss food

industry. Economic sensitivity analysis and monitoring steam profiles for the HTHP and storage sizing were crucial, with pinch analysis supporting decision-making.

- The **ELSA case study (Appendix 6, Chapter 3)** focused on using waste heat from chillers to supply a heat pump for the cleaning-in-place (CIP) system. The analysis indicated that steam demand could be avoided and replaced with lower-temperature heat from conventional heat pumps. However, the concept lacked proven feasibility and was hindered by an unfavourable context, as process steam was already largely supplied by a wood chip boiler. The baseline data obtained were insufficient, relying on assumptions to estimate heat needs based on limited measurements.
- **Overall**, not all case studies met the expected results, but they provided valuable **lessons learned** and helped **communicate the potential of emerging HTHP technologies** capable of supplying heat above 100 °C. A common challenge was the lack of baseline data, which was addressed through measurement campaigns and site visits to establish a reliable foundation. Some information was updated over time, reflecting the project's progress.

A **simple MS Excel-based economic model** was developed to assess a **'Go/No-Go' decision on HTHP integration** at an industrial site (**Appendix 7, HTHP Evaluation Tool, User Instructions, Excel File**). The Excel File with brief user instructions is available for download from the SWEET DeCarbCH Website[3].

This **HTHP Evaluation Tool** is designed to provide an indication of financial feasibility with limited input information. It assumes that a gas boiler investment is depreciated and remains in place for production redundancy or other uses (e.g., start-up, peak loads). It evaluates economic feasibility using **key input parameters,** such as electricity and gas prices, operating hours, heating capacity, temperature levels, investment and maintenance costs, interest rates, and CO_2 emission factors. **Output parameters** include COP, estimated investment and operating costs, CO_2 emissions reduction, annual cost savings, and payback periods.

The tool was tested on preliminary integration concepts for the case studies of **Gustav Spiess (sausage cooking), Cremo (milk drying), and ELSA (CIP process)**, although further validation is needed for more accurate estimations of the payback periods.

[3] https://www.sweet-decarb.ch/decarbonization-tools (HTHP_Evaluation_Tool_Annex_58_HTHP-CH.xls, User Instructions)

3 Conclusions and outlook

HTHPs have **significant potential** for decarbonizing **industrial process heat** at increasing temperature levels, utilizing **excess heat** to **reduce primary energy consumption, lower CO_2 emissions,** and achieve **economic benefits**.

The **HTHP market** is expanding with the growing adoption of **SGHPs.** Further efforts are required to **scale** and **diversify implementations** to meet **industrial decarbonization** targets. A **detailed process data analysis** is essential **for better selecting and sizing HTHPs** and **thermal energy storage** systems. **Collaboration** among **technology providers, end-users, planners, policymakers, and R&D organizations** is crucial for overcoming barriers and maximizing **adoption**.

The **HTHP workshop** with Swiss industrials highlighted **the technical, financial, and policy challenges associated with HTHP adoption, but it also confirmed significant potential in the industrial sector, particularly in the food and beverage processing industry**. Future efforts should focus on reducing investment risks, expanding industry knowledge, and leveraging financial incentives to accelerate market adoption.

A **survey** of 20 respondents revealed key insights into **the adoption of HTHP**. Steam was identified as the most relevant heat supply medium above 100 °C (81%). HTHP units with heating capacities ranging from 500 kW to 10 MW were considered to have high industrial potential.

The **main barriers** to adoption are l**ow gas prices** and a **lack of technical knowledge** among planners, which limit the effective integration of HTHPs. Recommended actions to **promote HTHPs** include **raising awareness of available products** and **real-world case studies, providing training**, expanding the availability of efficient, standardized HTHP products with natural refrigerants, implementing **financial incentives**, a CO_2 tax increase, and restrictions on fossil fuels, as well as accelerating electricity decarbonization.

In the coming years, efforts shall be put on:

- **Deploying and demonstrating HTHPs** in industrial applications,
- **Strengthening supply chains** and expanding available solutions,
- **Engaging industrial end-users** to support process decarbonization up to **200 °C,**
- **Raising knowledge** on the potential of **optimal HTHP integration** (Pinch analysis).

From a research perspective, the following topics are of major interest to HTHPs:

- **Demonstration of HTHPs** for **steam generation** in the industry (e.g., combined with MVR),
- **Experimental investigations** on **scaling effects** of HTHPs,
- **Increasing efficiency (COP)** through **multi-stage cycles** and **optimized cycle configurations** (e.g., **transcritical cycles**),
- **Application of natural refrigerants** such as hydrocarbons, CO_2, ammonia, water, and helium (i.e., Stirling cycles),
- **Development of optimized refrigerant mixtures** for **high-efficiency heat pumps**, tailored to the **temperature requirements of individual industrial processes,** as well as **to best fit temperature glides** in the streams,
- **Execution of techno-economic analyses** and implementation of **business models**.

4 National and international cooperation

An **HTHP workshop** was held on March 24, 2023, at the **Swiss Federal Office of Energy (SFOE)** in Ittigen, gathering **70 participants** from various industries and research institutions (**Appendix 8, Minutes from the HTHP Workshop**). Experts presented the latest advancements in HTHP applications, market developments, process integration methods (e.g., Pinch Analysis), and case studies (see the links to presentations in **Section 5.1**). The event also provided an opportunity to discuss industry decarbonization strategies and funding opportunities.

The **results of the HTHP-CH project** were widely disseminated through webinars, workshops, conferences, and publications. Between 2022 and 2024, the project contributed to **9 peer-reviewed journal papers, 27 conference presentations, over 16 talks, and 1 awarded Master's thesis.** Several workshops and webinars attracted global participants, strengthening Swiss research in HTHPs.

Key dissemination events included:

- **HTHP Workshop with Industrial Companies** (24/03/2023, Ittigen) (**Appendix 8**)
- **Webinars on Steam-Generating Heat Pumps** (01/03/2023 and 18/03/2024, online) (Chapter 5, Sections 5.2 and 5.3)
- **WP-Tagung 2024 in Bern** (26/06/2024) – Posters and an industry overview article (Chapter 5, Section 5.5)
- **IEA HPT Magazine Article** (30/04/2024) – Joining Forces to Encourage HTHPs in Swiss Industries (Chapter 5, Section 5.6)

As a **final event, the Webinar on HTHP Integration in Swiss Industrial Processes** (07/11/2024) attracted **over 330 interested participants from 26+ countries,** including researchers, engineers, product managers, project leaders, and executives. The webinar slides and the video recordings are available on the **SWEET DeCarbCH YouTube channel** (Chapter 5, Section 5.4).

The Swiss participation in the **IEA HPT Annex 58** contributed to a range of valuable outputs, including joint reports, presentations, conference workshops, magazine articles, and online dissemination webinars. Download versions of the task reports can be accessed via the links in **Section 5.7**, including the video recording of the **Final Webinar** on 23 April 2024, presenting the main outcomes of the **IEA HPT Annex 58 on High-Temperature Heat Pumps**.

5 Publications and other communications

The HTHP-CH project outcomes have been disseminated through several webinars, workshops, conferences, and papers.

5.1 HTHP Workshop with industrial companies (24/03/2023, Ittigen)

The workshop presentations are available online (https://www.sweet-decarb.ch/events/event/high-temperature-heat-pump-event). The presentations were recorded, and the videos are available upon request (contact OST).

- Introduction | SFOE
- Swiss National Market (Synthesis of Annex 58 Task 1 Report | OST
- Overview of HTHP technologies (available products > 100°C) | CSD & OST
- Demonstration case studies from IEA HPT Annex 58 | EPFL
- Pinch Analysis for practice and HTHP integration | part 1 |EPFL
- Pinch Analysis for practice and HTHP integration | part 2 | HEIG-VD
- Case Study Gustav Spiess AG HTHP Integration in Meat Production

5.2 Webinar on Steam Generating Heat Pumps (01/03/2023, online)

The webinar organized by OST-IES provided valuable insights into the latest advancements in steam-generating heat pumps. The webinar was recorded, and the videos are available on the SWEET DeCarbCH YouTube channel (Introduction | Steam Generating Heat Pumps Webinar 2023 - YouTube)

- Introduction | OST | Steam Generating Heat Pumps Webinar 2023
- Piston Steam Compressors to reach Process Heat up to 40bar/250°C | Spilling | Steam Generating Heat Pumps Webinar 2023
- Vapor compression heat pumps with PILLER MVR technology | | Steam Generating Heat Pumps Webinar 2023
- Integration of MVR-HP systems in industrial thermal processes | EPCON | Steam Generating Heat Pumps Webinar 2023
- Innovative MVR solution to generate steam for industrial processes requiring temperatures above 150°C | ToCircle | Steam Generating Heat Pumps Webinar 2023

5.3 Webinar on Steam Generating Heat Pumps (18/03/2024, online)

The webinar organized by OST-IES attracted more than 570 participants from over 42 countries. The participants were mainly researchers, but also sales engineers, process engineers, product managers, project leaders, and decision-makers, such as CTOs and CEOs. The recordings are now available on the SWEET DeCarbCH YouTube channel (Steam Generating Heat Pumps Webinar 2024 - YouTube). The PDF presentation slides are available for download.

- Introduction, Cordin Arpagaus, OST, Institute for Energy Systems (IES), Switzerland, Recording, PDF slides
- CO_2-neutral process steam for industry: Model-based analysis of technologies and strategies, Dennis Roskosch, ETH Zurich, Switzerland, Recording, PDF slides

- Transforming air compressor energy into process value for steam compression, Conrad Latham & Manuel Vandevoorde, Atlas Copco, Belgium, Recording, PDF slides
- Integration of a 1.6 MW steam supplying heat pump into the feed production process, Christian Schlemminger & Michael Bantle, ANEO, Norway, Recording, PDF slides
- Testing and modeling of a steam-generating heat pump at up to 175 °C (SuPrHeat project), Martin Pihl Andersen, DTU, Denmark, Recording, PDF slides
- Demonstration of a full-scale industrial heat pump producing steam above 140 °C, Wouter de Vries, TNO, The Netherlands, Recording, PDF slides
- High-temperature heat pump test result and further development of high-speed centrifugal compressors for steam production, Mogens Weel, Weel & Sandvig, Denmark, Recording PDF slides
- Steam compressor technology and development: a general overview, Hans Madsbøll, Danish Technological Institute (DTI), Denmark, Recording, PDF slides
- Decarbonizing industry with Stirling-cycle steam generating heat pumps, Arne Høeg, Enerin, Norway, Recording, PDF slides
- Wrap-up & Conclusions, Cordin Arpagaus, OST, Institute for Energy Systems (IES), Switzerland, Recording PDF slides

5.4 Webinar on Integration of HTHPs in Swiss Industrial Processes (07/11/2024, online)

This webinar was conducted by the Swiss HTHP-CH project team (OST, CSD, HEIG-VD, EPFL) and attracted more than 330 interested parties from over 26 countries. The webinar recordings are available on the SWEET DeCarbCH YouTube channel (https://www.youtube.com/@sweetdecarbch, Integration of High-Temperature Heat Pumps in Swiss Industrial Processes HTHP CH 2024 -part1), and the PDF presentation slides are available for download.

- Introduction (Nicole Calame-Darbellay, CSD), Recording, PDF Slides
- Guideline for HTHP integration (Cordin Arpagaus, OST), Recording, PDF Slides
- Case study ELSA: Integration concept and status (Pierre Krummenacher, HEIG-VD), Recording, PDF Slides
- Case study Cremo: Integration concept and status (Nicole Calame-Darbellay, CSD), Recording, PDF Slides
- Case study Gustav Spiess: Integration concept and status (Cordin Arpagaus, OST), Recording, PDF Slides
- Web-based integration tool: How to use it and demonstration of case studies (Daniel Flórez-Orrego, EPFL), Recording, PDF Slides
- Wrap-up & Lessons-learned (Cordin Arpagaus, OST), Recording, PDF Slides
- Poll and Q&A Chat, Recording

5.5 Posters and Report at the WP-Tagung 2024 (26/06/2024, Bern)

The proceedings of the WP-Tagung 2024, with the posters and overview report, are available here.

- Arpagaus, C., Bless, F., Bertsch, S.S.: Übersicht zu Industrie- und Großwärmepumpen, 30. Tagung des BFE-Forschungsprogramms «Wärmepumpen und Kältetechnik», 26. Juni 2024, Eventfabrik Bern, Link to Proceedings (Paper, p. 69-88)
- Arpagaus, C., Bless, F., Bertsch, S.S., Jansen, Ch.: Integration einer dampferzeugenden Wärmepumpe in einer Schweizer Fleischfabrik, 30. Tagung des BFE-Forschungsprogramms «Wärmepumpen und Kältetechnik», 26. Juni 2024, Eventfabrik Bern, Link to Proceedings (Poster, p. 163)
- Arpagaus, C., Bless, F., Bertsch, S.S., Maibach, Ch.: CO_2-Hochtemperatur-Wärmepumpe (HTWP) in der Produktion von veganen Alternativen zu Käse und Milchprodukte, 30. Tagung des BFE-Forschungsprogramms «Wärmepumpen und Kältetechnik», 26. Juni 2024, Eventfabrik Bern, Link to Proceedings (Poster, p. 169)
- CSD INGÉNIEURS, Calame, N.: Practical integration of steam-generating heat pumps in industrial processes, 30. Tagung des BFE-Forschungsprogramms «Wärmepumpen und Kältetechnik», 26. Juni 2024, Eventfabrik Bern, Link to Proceedings (Poster, p. 167)
- Florez-Orrego, D., Dardor D., Ribeiro-Domingos, M., Cortvriendt, L., Platteau C., Maréchal, F.: A web-based decision support tool for the design and integration of industrial high-temperature heat pumps, 30. Tagung des BFE-Forschungsprogramms «Wärmepumpen und Kältetechnik», 26. Juni 2024, Eventfabrik Bern, Link to Proceedings (Poster, p. 161)
- Krummenacher, P.: Industrial heat pump integration: Process analysis is key! Case study: CIP station at ELSA industrial dairy, 30. Tagung des BFE-Forschungsprogramms «Wärmepumpen und Kältetechnik», 26. Juni 2024, Eventfabrik Bern, Link to Proceedings (Poster, p. 165)
- Möhr, E., Bertsch, S., Bless, F.: Gross-Wärmepumpe für prozessintegrierten Einsatz, 30. Tagung des BFE-Forschungsprogramms «Wärmepumpen und Kältetechnik», 26. Juni 2024, Eventfabrik Bern, Link to Proceedings (Poster, p. 171)

5.6 Publications by the HTHP-CH team

Journal Papers

- Bever, P.-M., Bless, F., Arpagaus, C., Bertsch, S.S.: High-Temperature Heat Pumps for Industrial Use, Chemie Ingenieur Technik, 96, 8, 1071-1084, https://doi.org/10.1002/cite.202300241
- Cortvriendt, L., Florez-Orrego, D., Maréchal, F., Bongartz, D., Data-driven systematic methodology for predicting optimal heat pump integration based on temperature levels and refrigerants. Energy Conversion and Management, 326, 15 February **2025**, 119495, https://doi.org/10.1016/j.enconman.2025.119495
- Flórez-Orrego, D., Domingos, M. E. G., Maréchal, F. Techno-economic and environmental analysis of high temperature heat pumps integration into industrial processes. Sustainable Energy Technologies and Assessments, 60, **2023**, 103560, https://doi.org/10.1016/j.seta.2023.103560
- Dardor, D., Flórez-Orrego, D., Terrier, C., Ribeiro Domingos, M., Platteau, C., Silva, J.C., Lopez, M., Maréchal, F., ROSMOSE: A web-based decision support tool for the design and optimization of industrial and urban energy systems. Energy, 304, 30 September **2024**, 132182, https://doi.org/10.1016/j.energy.2024.132182
- Jeßberger, J., Arpagaus, C., Heberle, F., Brendel, L., Bertsch, S.S., Brüggemann, D.: Experimental Investigations of Upscaling Effects of High-Temperature Heat Pumps with

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- Sulaiman, A.Y., Cotter, D., Arpagaus, C., Hewitt, N.: Theoretical Evaluation of Energy, Exergy, and Minimum Superheat in a High-Temperature Heat Pump with Low GWP Refrigerants, International Journal of Refrigeration, available online 2 June 2023, https://doi.org/10.1016/j.ijrefrig.2023.06.001
- Vieren, E., Demeester, T., Beyne, W., Magni, C., Abedini, H., Arpagaus, C., Bertsch, S., Arteconi, A., De Paepe, M., Lecompte, S. (2023): The Potential of Vapor Compression Heat Pumps Supplying Process Heat between 100 and 200 °C in the Chemical Industry, Energies, 16(18), 6473, https://doi.org/10.3390/en16186473

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- Arpagaus, C., Bless, F., Bertsch, S.S.: Übersicht zu Industrie- und Großwärmepumpen, 30. Tagung des BFE-Forschungsprogramms «Wärmepumpen und Kältetechnik», 26. Juni 2024, Eventfabrik Bern, Link to Proceedings (p. 69-88)
- Arpagaus, C., Paranjape, S., Nertinger, S., Tietz, R., Bertsch, S.S.: Business models for high-temperature heat pumps, HTHP Symposium 2024, 23-24 January 2024, Copenhagen, Denmark, Link to Book of Presentations
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- Arpagaus, C., Bless, F., Bertsch, S., Krummenacher, P., Flórez-Orrego, D.A., Pina, E.A., Maréchal, F., Calame Darbellay, N., Rognon, F., Vesin, S., Achermann, P., Jansen, C.: Session Keynote: Integration of High-Temperature Heat Pumps in Swiss Industrial Processes (HTHP-CH) (494), 14th IEA Heat Pump Conference, 15-18 May **2023**, Chicago, Illinois, USA (Paper download)
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- Arpagaus, C.: A clean industrial era: Market, technology, and application potentials of high-temperature heat pumps, Webinar by Electrification Academy, 4 December 2024, Download PDF Presentation, Link to the Webinar Recording
- Arpagaus, C.: Pompe di calore ad alta temperatura e di grande potenza, Convegno dell'Associazione svizzera delle pompe di calore 2024, 28 maggio 2024, PalaCinema di Locarno, Programma
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- Arpagaus, C.: 2024 High-Temperature Heat Pumps Update, Australian Alliance for Energy Productivity (A2PH) Webinar, 6 March 2024, YouTube Video, Presentation Slides
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Master Thesis

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- Bertsch, S. and Arpagaus, C.: High-temperature heat pumps are on the rise - Why is their market uptake slow? Heat Pumping Technologies HPT MAGAZINE, Vol. 41 No 1/2023

5.7 Reports and Webinar from IEA HPT Annex 58

The IEA HPT Annex 58 dissemination activities provided valuable joint reports, presentations, conference workshops, magazine articles, and online webinars. Download versions are available via the provided links.

IEA HPT Task Reports Downloads

- Task 1 report – Technologies (Report no. HPT-AN58-2, 178 pages, August 2023)
- Task 2 report – Integration Concepts (HPT-AN58-3, 92 pages, April 2024)
- Task 3 report – Applications and Transition (HPT-AN58-4, 35 pages, March 2024)
- Task 4 report – Definition and testing of HP specifications (HPT-AN58-5, 54 pages, March 2024)

Final Report

- Final Report (HPT-AN58-1, 35 pages, November 2024)
- Summary (HPT-AN58-2, 2 pages, December 2024)

Final Webinar IEA HPT Annex 58 (23/04/2024)

The final webinar (Outcomes on HPT Annex 58 High-Temperature Heat Pumps) on 23 April 2024 attracted over 230 attendees from across the globe and focused on the results of Tasks 1, 2, 3, and 4. The key highlights of the webinar can be summarized as:

- A thorough technology review showcasing over 35 heat supply technologies operating above 100 °C, or even up to 200 °C.
- Real-world demonstration cases featuring 15 examples spanning over various industries.
- Integration concepts detailing options for integrating HTHPs into over 10 industrial processes.
- A comprehensive guideline designed to navigate the transition towards heat pump-based process heating.
- Recommendations for defining and testing heat pump specifications, offering valuable insights for industry stakeholders.

The webinar video recording and copies of all webinar presentations are available online. Additionally, all information pertaining to IEA HPT Annex 58 can be accessed via the homepage (https://heatpumpingtechnologies.org/annex58).

6 Appendix

Appendix 1	Swiss Market Report
Appendix 2	Factsheets HTHP Technologies
Appendix 3	Factsheets HTHP Demonstration Cases
Appendix 4	Integration Concepts
Appendix 5	Integration Guidelines Report
Appendix 6	Case Studies Report
Appendix 7	HTHP Evaluation Tool (User Instructions and Excel File)
Appendix 8	Minutes Report from HTHP Workshop

All attachments can be downloaded at https://www.aramis.admin.ch/Texte/?ProjectID=49514