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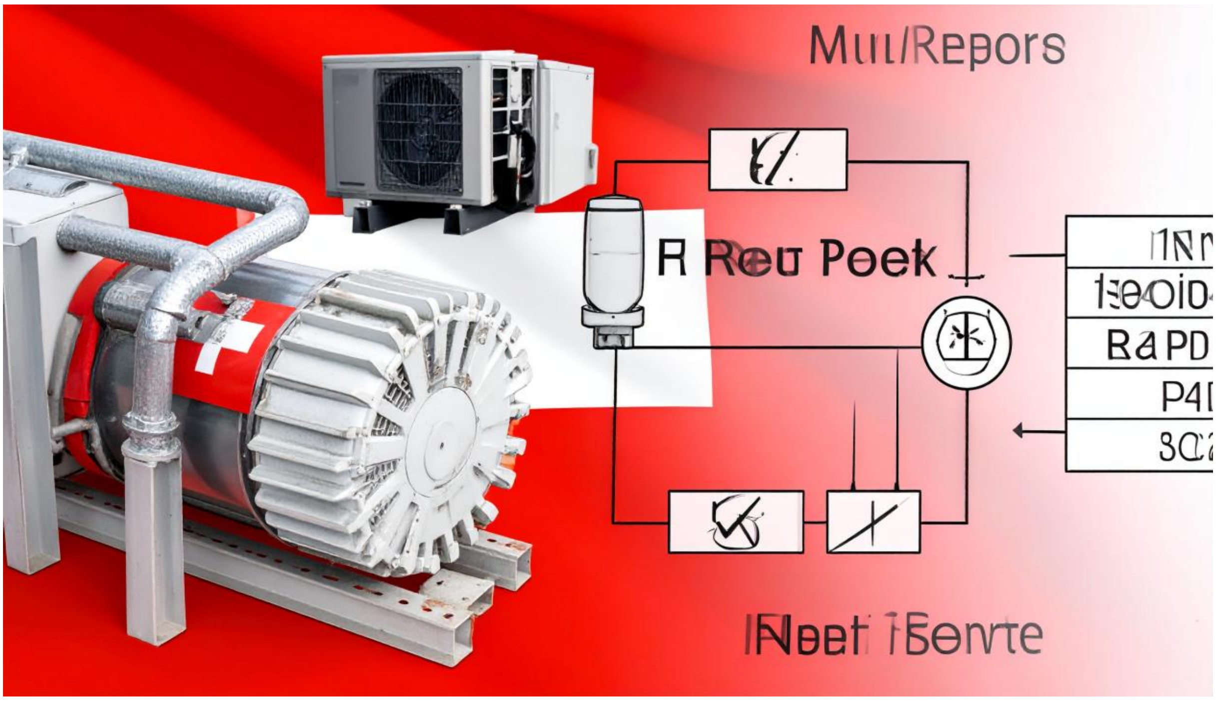
Final report from 31 August 2023

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

Appendix 1

Swiss Market Report



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This is an appendix to the summary report on the project "Annex 58 HTHP-CH – Integration of HTHPs in Swiss Industrial Processes". The report and other appendices can be downloaded at https://www.aramis.admin.ch/Texte/?ProjectID=49514.

Swiss Market Report

(= Extract from the IEA HPT Annex 58 Task 1 Report – Technologies
Report no. HPT-AN58-2, 178 pages, August 2023
https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2023/09/annex-58-task-1-technologies-task-report.pdf

4.13. Switzerland

This chapter provides an overview of Switzerland's national HTHP industry and ongoing research, development, demonstration, and funding activities.

4.13.1. Overview of the National HTHP Industry

According to the authors' best knowledge, only two manufacturers in Switzerland offer HTHP technology with supply temperatures above 100°C, namely FRIOTHERM AG, headquartered in Frauenfeld, and MAN Energy Solutions AG from Zurich. Their focus is primarily on tailor-made large-scale heat pumps with heating capacities in the MW range. Therefore, the main driving force behind the technical developments in their compressor technologies represents a unique selling proposition.

Friotherm AG [94] has over 30 years of operating experience with large heat pumps in district heating networks using its core Unitop™ centrifugal compressor technology. Figure 4-70 gives an overview of Friotherm AG's HTHP technology, including 1-stage and 2-stage customized heat pumps with heating capacities from 3 MW to 35 MW, delivering water temperatures up to 120 °C from various liquid heat sources in a wide temperature range.

As a specialty, Figure 4-70 (C) shows a 25 MW heat pump producing superheated water at 137 °C for low-pressure steam generation. This steam-generating heat pump was designed for a heat source of 55/40 °C and a heat sink of 130/137 °C. It operates with the refrigerant R-1233zd(E) and achieves a COP of approx. 2.5. The dimensions are approx. 18 x 15 x 10 m.

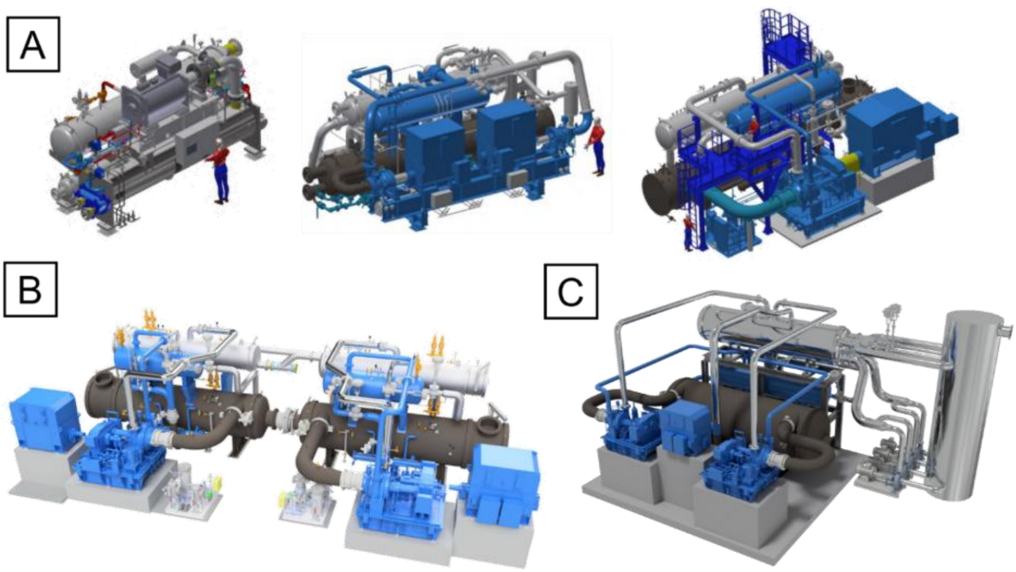


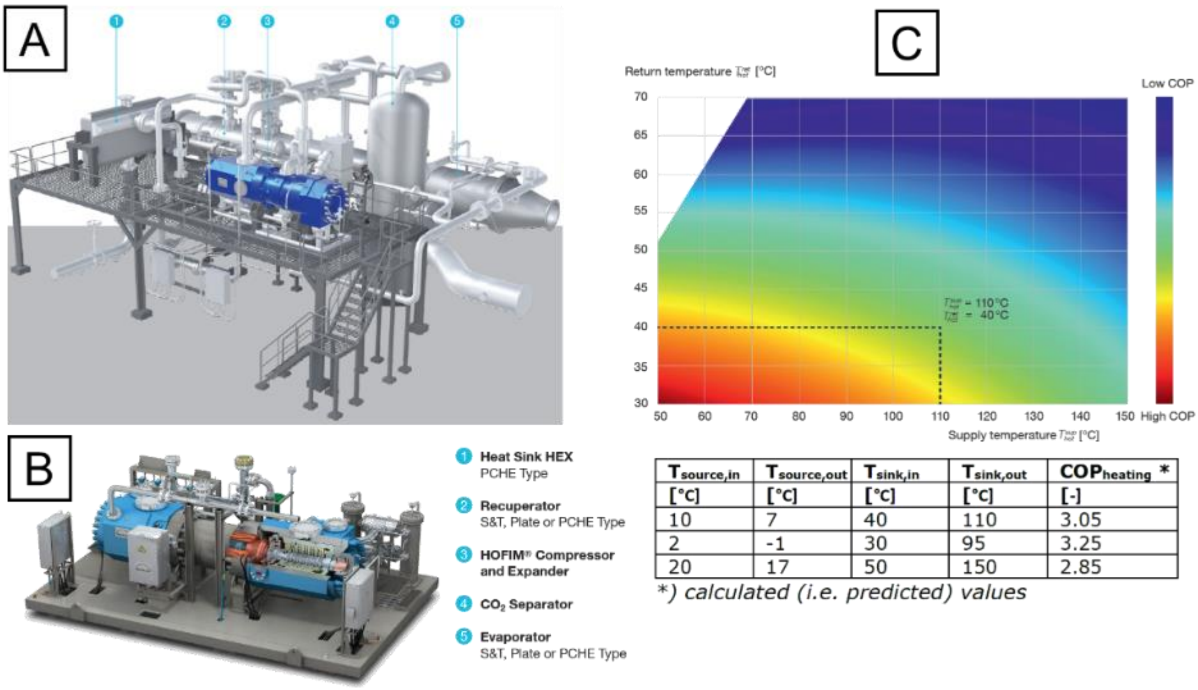
Figure 4-70: Application range of FRIOTHERM AG heat pumps with heat supply temperatures above 100 °C. (A) 1-stage and 2--stage tailor-made heat pumps with centrifugal compressor, heating capacity from 3 MW to 35 MW, various liquid heat sources in a wide temperature range, supplying hot water temperatures up to 120 °C (higher on request). (B) Customized double-group heat pump with dimensions of 22.5 x 10.8 x 6.8 m (L x W x H) and up to 35 MW heating capacity. (C) Heat pump producing superheated water at 137 °C for the low-pressure steam generation with a heating capacity of 25 MW, heat source 55/40 °C, heat sink 130/137 °C, R-1233zd(E) refrigerant, COP of around 2.5, dimensions approx. 18 x 15 x 10 m (Pictures courtesy of Friotherm AG, Frauenfeld, Switzerland).

In 1986, Friotherm AG (Sulzer) introduced the first steam-generating heat pump consisting of a Unitop® heat pump with two Uniturbo 22 BX turbo compressors connected in series. The technical data suggested a steam temperature of 123 °C at 59 °C/56 °C heat source (inlet/outlet) and a COP of 2.7.

The employed R-114 refrigerant, which is prohibited today due to ozone depletion, has been replaced by low-GWP HFO refrigerants. Thus, steam-generating heat pumps in the MW range with turbo compressors will directly serve the low-pressure steam of an industrial company.

MAN Energy Solutions Schweiz AG [95] supplies the heat pump solution HPU that runs with CO_2 as a working medium in an optimized transcritical cycle. This HTHP unit can generate temperatures from 0° C up to 150 °C, up to 50 MW of thermal heat, and 30 MW of cold. The core technology is the High-Speed Oil-Free Integrated Motor compressor (HOFIM®), which incorporates an active magnetic bearing system that ensures a wide operating range, high reliability, availability, and a fast start-up and shut-down.

Figure 4-71 (A, B, and C) shows an example of the MAN heat pump, the HOFIM® compressor details, and its operating range and efficiency. At nominal reference conditions with a heat sink supply/return temperature of 110 °C/40 °C and heat source temperature of 10 °C/7 °C, the MAN HPU43 type heat pump (with 20 tons CO_2 refrigerant charge) reportedly achieves a heating COP of 3.05 and a COP for cooling of 2.05 (combined around 5.1). The transcritical cycle is especially suited for significant heat sink temperature glides above 40 K.



$T_{source,in}$ [°C]	$T_{source,out}$ [°C]	$T_{sink,in}$ [°C]	$T_{sink,out}$ [°C]	$COP_{heating}$ * [-]
10	7	40	110	3.05
2	-1	30	95	3.25
20	17	50	150	2.85

*) calculated (i.e. predicted) values

Figure 4-71: (A) Example of a MAN Heat Pump. (B) Typical HOFIM™ (High-speed Oil-Free Integrated Motor compressor) skid with up to 16 MW electrical power. (C) Predicted performance map (COP heating) for different operating conditions and COP values as a function of heat sink supply and return temperatures for constant source temperatures (Pictures courtesy of MAN Energy Solutions Schweiz AG, Zurich).

MAN's electro-thermal energy storage system (MAN ETES) [96] integrates heat and cold production, storage, and reconversion into electricity by an expander. Therefore, the ETES system is a complete energy management system that allows a broad range of applications and enables sector coupling. So far, MAN Energy Solutions is mainly active in district heating and is about to deliver the first cross-sectoral ETES technology to the Danish port city of Esbjerg [97] with an overall heating capacity of 50 MW.

4.13.2. Realized HTHP applications examples in Switzerland

Some industrial heat pumps installed in Switzerland can produce heat with temperatures higher than 100 °C but operate at a lower supply temperature. Three application examples reach 90 to 95 °C and a CO_2 heat pump prototype up to 119 °C (Figure 4-72).

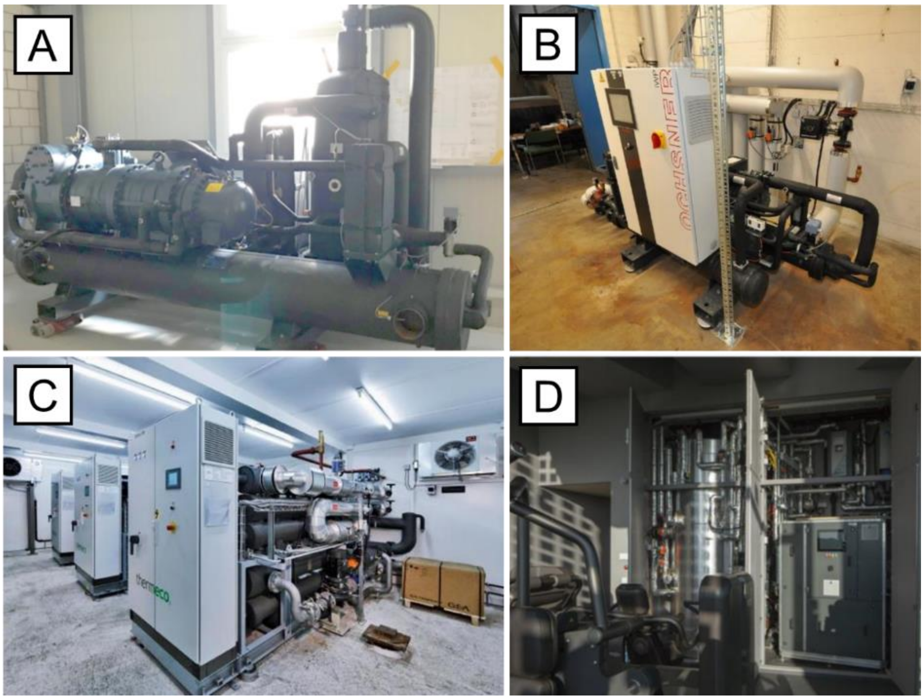


Figure 4-72: (A) HTHP installed at the mountain cheese factory Gais in Appenzell working with mildly flammable refrigerant R-1234ze(E) in an economizer cycle, Type IWWHS 570 ER6c2 from Ochsner Energie Technik GmbH, 520 kW heating capacity, screw compressor, heat source (in/out) 18/14 °C, heat sink (in/out) 82/92 °C or 55/65 °C). (B) HTHP installed at GVS Landi in Schaffhausen, Type ISWHS 60 ER3 from Ochsner Energie Technik GmbH, 63 kW heating, and 48 kW cooling capacity, ÖKO 1 (R-145fa) refrigerant, screw compressor, heat sink from 80 to 95 °C, heat source 37 °C, COP heating of 4.2. (C) Three CO_2 heat pumps of the type thermeco2 HHR 260 [98] *at the Slaughterhouse in Zurich provide hot water of 90 °C for slaughtering and cleaning purposes. (D) The CO_2 heat pump prototype at Empa NEST in Dübendorf delivers heat up to 119 °C for a wellness sauna.*

For example, at the mountain cheese factory Gais in Appenzell [99], an industrial HTHP from Ochsner Energie Technik GmbH (AT) [100], [101] (Type IWWHS 570 ER6c2) (Figure 4-72, A) transforms waste heat from the neighboring data center into process heat of up to about 95 °C for heating and processing milk. The installed heat pump can produce > 100 °C heat but runs at a lower production temperature. It saves the mountain cheese factory about 1.5 million kWh of natural gas annually, corresponding to around 300 tCO_2/year emissions savings. The HTHP features an economizer cycle with steam injection into a two-stage screw compressor, providing an efficient solution for high-temperature lifts. The nominal heating capacity is 520 kW. Depending on the operating conditions, the heating COP ranges from 2.55 to 2.85 at a 74 K temperature lift (W18-14/W82-92) and from 3.75 to 4.20 at a 47 K lift (W18-14/W55-65).

At GVS Landi AG in Schaffhausen [102], another HTHP is installed (Figure 4-72, B) that could potentially deliver supply temperatures > 100 °C. It recovers waste heat from air-coolers of the refrigeration plants (used for cooling warehouses) to generate process water for cleaning a bottling machine and wine tanks [103] in the wine cellar needs. Installed is an HTHP from Ochsner (Type: ISWHS 60 ER3, with 63 kW heating capacity) with a screw compressor, economizer cycle, and refrigerant ÖKO 1 (R-245fa). The investment has reduced CO_2 emissions by 30% with a payback period of 4 years (at relatively moderate investment costs of CHF 120,000). The heating COP is about 4.2 at a heat source of 37 °C and a heat sink of 80 to 95 °C.

At the slaughterhouse in Zürich, three CO_2 heat pumps (thermeco2 HHR 260, ENGIE) have operated since 2011 with a heating capacity of 800 kW to heat water from approx. 30 °C to 90 °C for cleaning purposes and as feed water for a steam generator and the heating system. Twelve GEA CO_2 transcritical compressors drive the heat pumps. The heat pump system uses the waste heat from an existing ammonia refrigeration machine, an oil-cooled air compressor plant, and fan-coil units. EWZ [104] planned and operates the heat pump system. The COP of the HTHP is 3.4 at 90 °C/30 °C. In this way, fuel consumption could be reduced by 30% and the CO_2 emissions by 510 tCO_2/year.

A prototype CO_2 heat pump is installed in a research building of EMPA NEST for the wellness sauna application [105] (Figure 4-72, C). In cooperation with Scheco AG [106], a new CO_2 heat pump was designed and installed as a pilot system with different temperature levels for saunas, steam baths, and shower heating. Measurements are being carried out to optimize the overall HTHP system. Low return temperatures are crucial for efficiency. The system impresses with high temperatures on the refrigerant side (120 to 140 °C) and the consumer side (up to 119 °C). A maximum COP of 3.6 has been reached, but there is potential for improvement to reduce return flow temperature for higher heat pump efficiency. In another R&D project, Scheco AG has developed a water-brine heat pump for waste heat recovery from an electrolyzer for hydrogen production. The heating capacity is 54 kW, and a COP of 2.3 is achieved at 93 °C/100 °C (heat sink) and 35 °C/30 °C (heat source).

The market for HTHP in Switzerland is still in its infancy and has yet to be developed [107]. However, there are numerous system integrators. For example, Walter Wettstein AG Kältetechnik [108] is a leading manufacturer of refrigeration chillers and heat pumps for the industry, especially with ammonia (NH_3) as a natural refrigerant. Currently, the company offers R-717 heat pumps with a heating capacity of 0.2 to 20 MW with supply temperatures up to 85 °C. A HTHP solution with R-717/R-600 (n-butane) is in the technical clarification phase.
A realized example in the field of district heating in Switzerland is the district heating network of Gruyère Energie SA (GESA) in Bulle with a heat pump from Ochsner (Type IWWDS 540/540 R4c4) [109] and a heating capacity of 1.8 MW [110]. The heat pump uses waste heat from the Liebherr company and can operate up to 125 °C on the heat sink, but it works at W60/W90.

Besides closed-cycle HTHPs, MVR (Mechanical Vapor Recompression) is applied in Switzerland, and there are several operational examples, mainly focused on the food industry, including:

- Saline de Bex (Bex): Brine concentration for salt production
- Cremo (Villars-sur-Glâne): Milk concentration by evaporation for milk powder production
- Nestlé (Orbe): Coffee extract concentration for instant coffee production
- Ramseier (Sursee): Fruit juice concentration

Additional applications are currently being identified, e.g., in the concentration and drying of wastewater sludge. In addition, several Swiss companies also apply MVR for desalination plants [111].

Interestingly, MVR is a Swiss success story. The principle of MVR technology was invented [112] in Switzerland by Antoine-Paul Piccard (great-granduncle of the famous aeronaut Bertrand Piccard, known for his round-the-world balloon flight and Solar Impulse project) to produce salt by evaporation of brine at the Saline de Bex [113].

Figure 4-73 illustrates one of the early designs of the MVR by A.-P. Piccard for brine concentration installed in 1877 at Saline de Bex.

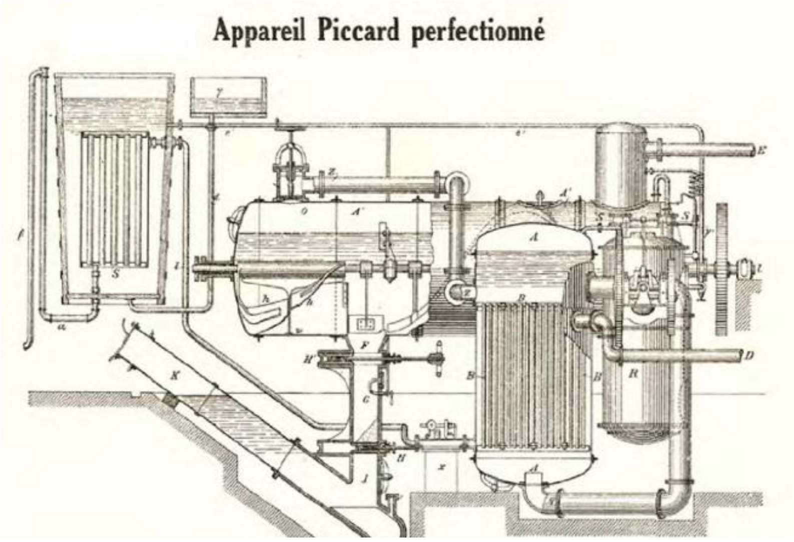


Figure 4-73: One of the early designs of mechanical vapour compression by A.-P. Piccard for brine concentration at the Saline de Bex (Excerpt from Georges Gavairon, June 2011, Le sel de A à Bex – Résumé de 500 ans d'histoire, de persévérance, d'ingéniosité, de compétence, de labeur et de passion aux Mines et Salines de Bex [114]*).*

After the invention of the principle, A.-P. Piccard improved technology several times. Later, MVR technology was applied in numerous other salt plants in Switzerland, as reviewed by Martin Zogg in "History of Heat Pumps: Swiss Contributions and International Milestones" [115]. Today, Switzerland's largest MVR systems are in operation in Riburg and Schweizerhalle, with a total evaporation capacity of about 80 MW. Presently, the MVR system for the production of salt at the Saline de Bex consumes approximately 500 kW of electrical power to upgrade 11'200 kg/h vapor from 1.29 to 2.25 bar (136 °C) and supplies about 7.4 MW of thermal energy to evaporate water from brine (Figure 4-74). The resulting COP is about 14.7.

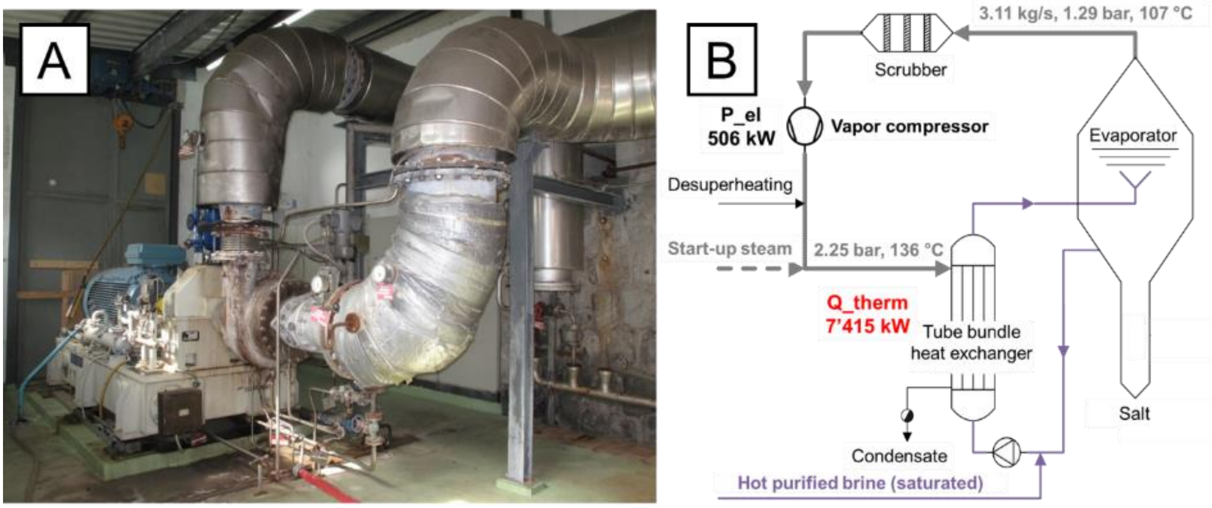


Figure 4-74: (A) Turbocompressor from MAN at Saline de Bex (Picture courtesy of Pierre Krummenacher). (B) Simplified schematic of the MVR installation at Saline de Bex (Source: Sulzer/Saline de Bex, adapted by Pierre Krummenacher, reproduced with permission of Salines Suisses).

Currently, most of the installed heat pumps in Switzerland are electrically driven. To the authors' knowledge, few (if any) large-capacity absorption heat pumps are in operation in Switzerland, although small/medium-capacity gas-fired heat pumps are available for HVAC applications. In addition, there is no Swiss statistic on absorption heat pump sales.
In addition, the opportunities for meaningful integration of thermally driven HTHPs in the industry are likely to be significantly lower than those of electrically driven HTHPs because thermally driven HTHPs require additional features, such as a particular shape of the Grand Composite Curve of the process/industrial site, which is less often fulfilled than for electrically driven HTHPs.

4.13.3. Overview of the Swiss national HTHP market and application potential

Figure 4-75 shows the sales statistics from FWS (Fachvereinigung Wärmepumpen Schweiz) [116] of the Swiss heat pump market in 2021 compared to gas and oil boilers, (A) in sales units and (B) in total installed heating capacity. The FWS statistically tracks air-water, brine-water, and water-water heat pumps. Heat pumps are well established in the lower capacity range for the residential sector (market share of over 90% in new buildings).
When multiplying the units with the heating capacity, it becomes clear that above 50 kW oil and gas boilers dominate the market regarding heat production volume, hence illustrating the decarbonization potential in the Swiss industry. Furthermore, Switzerland's cumulated numbers of gas and oil boilers cover a much larger share (1'025 MW) of the heating capacity than heat pumps (630 MW).

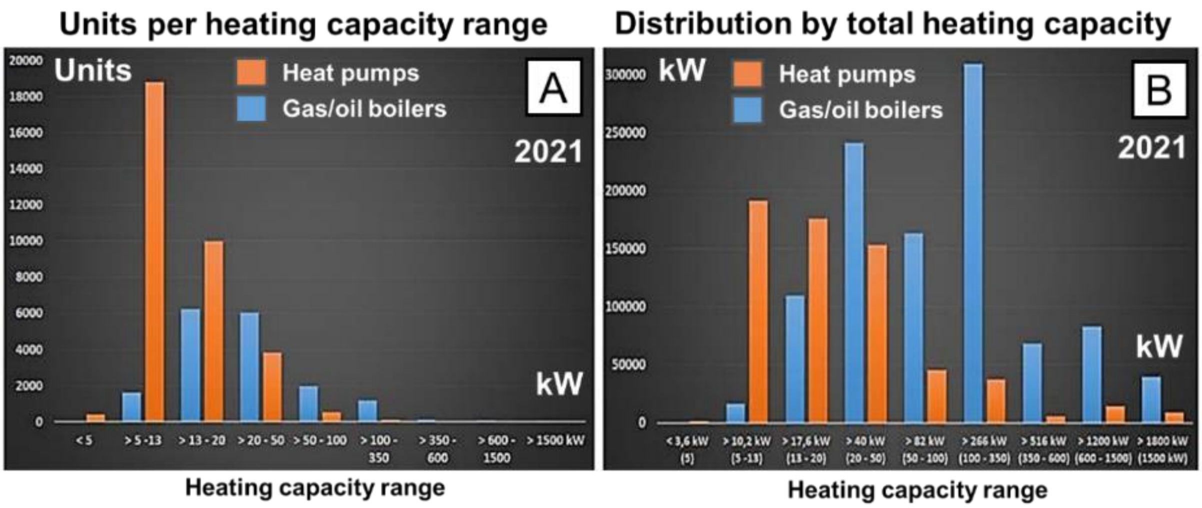


Figure 4-75: Statistics of the Swiss heat pump market (orange) compared to oil and gas boilers (blue) (A) in units of sales and (B) in cumulated heating capacity distributed by heating capacity range (Data: FWS, 2021).

According to FWS 2021 sales statistics, the number of sold heat pumps increased to an all-time high of 33'704 units compared to 28'064 in 2020, corresponding to an annual growth rate of 20%. Also, 73% of the sold heat pumps were air/water and 25.6% brine/water-based. There were 169 heat pumps sold with >100 kW heating capacity (around 0.5% of all units). Unfortunately, there needs to be more information about the temperature ranges of the heat sources and sinks. In addition, there are no statistics on MVR sales or specifically on industrial heat pumps.

Aside from space heating and hot water, the industry needs process heat for manufacturing, processing, and refining products. As shown in Figure 4-76 (A), according to the Swiss Federal Office of Energy (SFOE), the process heat demand in Swiss industry corresponds to around 86.8 PJ (24.1 TWh) or 56.1% of the total industrial final energy consumption (154.7 PJ or 43.0 TWh) (as of 2018).

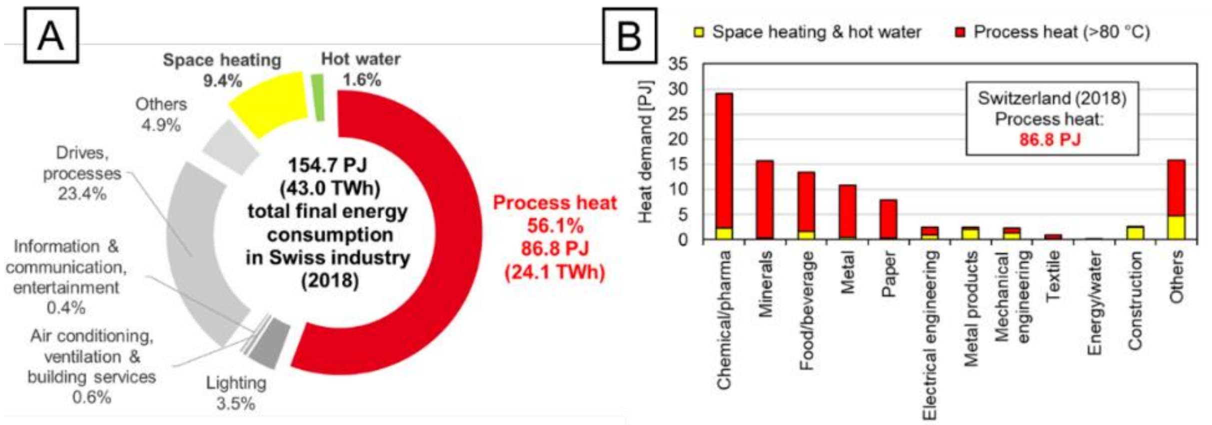


Figure 4-76: Process heat demand (>80 °C) in the Swiss industry (2018) (A) divided by industrial sector (B) showing the theoretical addressable market potential for industrial HTHPs (Data: SFOE, 2019).

The addressable potential using HTHPs in the Swiss industry can be roughly estimated based on the process heat demand and the share of process heat below 150 °C (Table 4-12).

According to Heat Roadmap Europe, the energy demand for process heat below 100 °C is about 222.5 TWh (9% of the total energy for industrial heat demand in Europe), and for process heat between 100 °C and 200 °C about 508 TWh (21%), which together corresponds to 30%. If this factor is applied to the Swiss industry, the process heat demand below 150 °C is 7'232 GWh/year.

Assuming in a pessimistic and an optimistic scenario that HTHPs could cover 10% and 50% of this, respectively, the process heat potential that can be covered by HTHPs is 723 and 3'616 GWh/year, i.e., approximately 3% to 15% of the industrial process heat demand (Table 4-12).

If the integrated HTHPs run with at least 5000 operating hours per year, this results in a total heating capacity of 145 to 723 MW and, with specific investment costs (incl. installation, without integration) of approx. 480 to 750 CHF per kW heating capacity, [117], [118] a potential investment volume of 69 to

542 million CHF for the Swiss industry. Assuming an average heating capacity per HTHP unit of 1 MW results in 145 to 723 HTHP units.

Table 4-12: Estimation of the potential addressable market for HTHPs in the Swiss industry.

Potential calculation for HTHPs in Switzerland				**Data source, remarks**
Swiss industry energy consumption	42,972		GWh	154.7 PJ (as of 2018, SFOE)
Process heat demand	24,107		GWh	56.1% [119]
Process heat demand < 150 °C	7,232		GWh	30% estimate, Heat Roadmap Europe [120]
Scenarios	Pessimistic	Optimistic		
Conversion change to HTHPs	10%	50%		Own estimate
Addressable process heat by HTHPs	723	3,616	GWh	
% of total process heat demand by HTHPs	3%	15%		
Heating capacity of installed HTHPs	145	723	MW	5,000 h/a operation assumed average
Electrical need for HTHPs	241	1,205	GWh	COP = 3, own estimate
Energy savings by HTHPs use	482	2,411	GWh	
Investment volume min	69	347	Mio. CHF	480 CHF/kW (Wolf et al., 2017)
Investment volume max	108	542	Mio. CHF	750 CHF/kW (Wolf et al., 2017)
HTHP units	145	723	Units	1 MW average size, own estimate

Target markets for decarbonizing process heat in Switzerland and with high potential for using HTHPs are the chemical/pharmaceutical, minerals, food/beverage, metal, and paper industries (Figure 4-76, B). The most promising sectors in terms of complementarity between available waste heat at 40 to 60 °C and process heat demand at 100 to 150 °C seem to be the chemicals and pulp/paper industries, where the use of industrial heat pumps can cover more than all the demand at these temperatures, and the food industry (25% coverage rate) [121]. In addition, the iron and steel industry also shows potential for waste heat recovery through industrial heat pumps.

Based on a study from EPFL [122], the most promising industrial sectors for heat pump integration are the food and beverage sector (overall carbon mitigation potential between 25 to 58% and payback times from 3 to 6 years), followed by the chemical sector (total of 22 to 74% emission reduction potential with a payback of 2.1 years).

Figure 4-77: Potential applications and target industrial sectors for industrial HTHPs [123].

Case studies for HTHPs can be found in particular in the dairy industry (evaporation, pasteurization) and biotechnology (distillation) for low-pressure steam generation (e.g., 120 °C). It was estimated that approximately 35% [124] of the total fuel energy consumption in the Swiss industry is used to meet the demand for steam, which could be supplied by low-pressure evaporation and MVR or HTHP systems [125], [126].

All in all, there is a significant application potential for tailor-made industrial HTHPs to end-users in the food/beverage, paper, metal, and chemical/pharmaceutical industries, especially for (low-pressure) steam generation, drying, preheating, distillation processes as well as pasteurization, sterilization, cooking, evaporation, or even washing or dyeing. Figure 4-77 illustrates potential applications and target industrial sectors for industrial HTHPs.

4.13.4. Funding programs for industrial heat pumps in Switzerland

There are several national funding programs at the federal level to accelerate the integration of heat pumps in the industry. However, the subsidies depend to a large extent on a legal basis. In general, funding programs are a dynamic field with details subject to change.

Following Switzerland's failed CO_2 energy law in 2021, a provisional CO_2 law now secures the legal basis until 2024. What the legal provisions will look like after that is still being determined. But, judging by the public debates, subsidies will likely play a major role in achieving the goal of net zero by 2050. However, it is still being determined what the subsidy share for heat pumps will be.

Table 4-13 gives an overview of a selection of funding programs for HPs for industrial process heat in Switzerland. Further information on the programs, program managers, financing, and subsidy conditions is available via the info links. For a more general overview of innovation promotion in the energy sector, the reader is referred to the admin.ch website.[24]

[24] https://www.bfe.admin.ch/bfe/en/home/research-and-cleantech/overview-of-innovation-promotion.html

Table 4-13: A selection of funding programs for industrial heat pumps in Switzerland (SFOE: Swiss Federal Office of Energy).

Funding program	Pinch Analyses	Heat Pumps for Process Heat	Klimaprämie (Climate bonus)	Pilot and Demonstration
Program Manager	EnergieSchweiz (SuisseEnergie)	EnergieSchweiz (SuisseEnergie)	Energie Zukunft Schweiz	SFOE
Financing	SFOE	SFOE	KliK Foundation	SFOE
Amount	Pre-analyses: max. 60% of total costs Pinch analyses: max. 40% of total costs	Max. 40% of additional costs compared to conventional technology (e.g., oil or gas boiler)	0.18 CHF/kWh heat About 360 CHF/kW heat at 2000 h annual operation	Up to 40% (60%) of non-amortizable supplementary costs
Criteria	Using PinCH-Software Trained experts Publication of findings (summary, final report)	Industrial process heat Payback > 4 years Funding request before construction starts Companies with a CO_2 tax exemption are examined individually.	Replacement of oil/gas boiler with heat pump Order not yet placed CO_2 savings to be transferred to Energie Zukunft Schweiz	Application potential Innovation content Pilot: TRL 4 to 7 Demonstration: TRL 7 to 9 Publication of findings (final report)
Infos	Website[25], Flyer[26]	Website[27], Flyer[28]	Website[29], Flyer[30],[31]	Website[32]

Pinch Analyses: The SFOE financially supports pinch analyses of up to 40% of total costs and pre-analyses of savings potential and pinch suitability covering up to 60% of the total costs. Depending on the data basis, a pinch analysis costs between 30 and 80 kCHF. Only analyses by experts with recognized training in pinch methodology (e.g., pinch software PinCH 2.0/3.0/3.5, Lucerne University of Applied Sciences and Arts)[33] are supported. The funding is associated with delivering a management summary or final report of the study results, which includes the technical measures derived with an estimate of investment costs and energy cost savings. The final reports will be made available on the

[25] https://www.energieschweiz.ch/beratung/pinch/ (DE) and https://www.suisseenergie.ch/conseil/pinch/ (FR)
[26] https://pubdb.bfe.admin.ch/de/publication/download/8357 (DE) and https://pubdb.bfe.admin.ch/fr/publication/download/8357
[27] https://www.energieschweiz.ch/prozesse-anlagentechnik/industrielle-waermepumpe/ (DE) and https://www.suisseenergie.ch/processus-technique-dinstallations/pompes-industrie/ (FR)
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[32] https://www.bfe.admin.ch/bfe/en/home/research-and-cleantech/pilot-and-demonstration-programme.html
[33] https://pinch-analyse.ch/en/pinch (EN) and https://pinch-analyse.ch/fr/ (FR)

SFOE's publications database[34]. The SFOE contribution is paid exclusively to the implementing company.

Heat Pumps for Process Heat: The "Heat Pumps for Process Heat" funding program started in 2021 and promotes the market entry of industrial heat pumps. It supports up to 40% of the additional investment costs of a heat pump (system and installation) compared to the costs of a conventional heating technology (e.g., oil or gas boiler). Engineering and monitoring costs can also be funded by up to 40%. The heat pump must generate process heat, and the funding request must be made before construction. In addition, the project must have a payback time of more than 4 years. Combining subsidies from other funding programs (e.g., KliK) is generally possible. In 2021, 4 projects with a total of approx. 500 kCHF were subsidized. In 2022, there were 4 projects funded with 700 kCHF in total. The SFOE actively promotes the funding program through a targeted information campaign, contacting potential companies directly and focusing on industries with strong net-zero targets. The goal is to reach 60% to 80% of this market. So far, SFOE is on track to achieve this goal. Today, the biggest hurdles tend to be technical, mainly that integrating a heat pump into the process is more complicated than a 1:1 replacement of the fossil heating system. Even in greenhouses, converting to fossil-free heating requires some system integration work. To address this issue, the SFOE will focus on easy-to-integrate solutions in the hope that these will create a larger market starting in 2023.

Klimaprämie (Climate bonus): The "Klimaprämie" provided by the Klik Foundation and managed by Energie Zukunft Schweiz AG is a subsidy program for renewable energy use in heating applications to replace natural gas or oil heating systems with heat pumps or wood heating systems in residential, office and commercial buildings, as well as in industrial heat generation. The climate bonus is calculated based on the previous annual fossil energy consumption and amounts to CHF 0.18/kWh, i.e., approx. CHF 1.8/L of heating oil or m^3 of natural gas saved, or approx. CHF 360/kW for 2000 h of annual operation. The climate bonus is not subject to an upper limit and offers new opportunities for large-scale systems. Up to funding of CHF 200’000, 50% of the amount is paid after commissioning and 50% after the first year of operation. For a large heat pump with a heating capacity >2 MW, a reference offer for the 1:1 replacement of fossil heating is required. Bivalent and multivalent systems are also eligible. Finally, the CO_2 savings achieved with the heat pump need to be transferred to Energie Zukunft Schweiz AG and cannot be the subject of any other compensation.

Pilot and Demonstration (P+D) projects: With the P+D program [127], the SFOE promotes the development and testing of new technologies, solutions, and concepts related to the economic and ecological use of energy, the transmission and storage of energy, and the use of renewable forms of energy. The P+D program acts as an interface between research and the market (Figure 4-78). The main funding criteria of P+D projects are substantial application potential and innovation content. A research partner (e.g., a University of Applied Science) is required to ensure the scientific nature of the P+D project. Funding covers the cost of the research partner. The maximum permissible financial support by the SFOE to P&D projects is up to 40% (in exceptional cases even 60%) of the non-amortizable supplementary costs. P+D projects with HTHP technology appear realistic, especially for heat pumps generating steam.

4.13.5. Research programs for HTHPs in Switzerland

Heat Pumps and Refrigeration: Under the research program Heat Pumps and Refrigeration [128], the SFOE defines "heat pumps with a broad, flexible temperature regime" and "innovative heat pumps for industrial processes" as current research priorities. HTHP technology fits into these priorities.

Buildings and Cities: The Buildings and Cities research program [129] aims to promote the further development of sustainability strategies with new technologies and an optimized interaction of energy production, storage, distribution, and consumption. In the 2020 call, the project HiTemHP [130] (Efficient use of HTHPs in old buildings and for renovations) from EMPA (Dübendorf) and Scheco AG (Winterthur) was approved. This project investigates CO2 HTHPs with supply temperatures up to 90 °C and how the heat pump system with heat source and sink must be designed to achieve a comfortable indoor climate and high energy efficiency.

SCCER EIP (Swiss Competence Center Energy Research - Efficiency of Industrial Processes): A major outcome of the finished SCCER EIP project [131] was research on HTHPs, published in a book

[34] https://pubdb.bfe.admin.ch/de/suche?keywords=&q=pinch

entitled Hochtemperatur-Wärmepumpen [132] and a well-cited review paper [1]. Apart from the theoretical analyses, a prototype HTHP was built at the OST Eastern Switzerland University of Applied Sciences with eco-friendly refrigerants reaching 70 °C to 150 °C heat sink temperature with a COP of 2.1 to 4.5 and a temperature lift of 30 K to 70 K. Although HTHP systems are already in operation, several market barriers have been identified, such as high specific investment costs, a limited number of HTHP manufacturers on the market, little experience among planners and end-users, and preconceptions about lifetime and suitability.

SWEET - SWiss Energy research for the Energy Transition: SWEET [133] is a funding program of the SFOE to accelerate innovations that are key to implementing Switzerland's Energy Strategy 2050 and achieving the country's climate goals. The funding program was launched in early 2021 and runs until 2032. One sponsored project is SWEET DeCarbCH (Decarbonisation of Cooling and Heating in Switzerland, www.sweet-decarb.ch) [134] with the University of Geneva as the host institution. Work package WP05 focuses on the optimal combination of existing and future technologies to achieve medium and high temperatures and cooling at different capacity levels. Furthermore, the technical solutions for industrial HTHP will be considered, and proposals for accelerated market introduction will be developed.

4.13.6. Selected R&D projects for HTHPs in Switzerland

Table 4-14 presents the most relevant national and international R&D projects of the Swiss partners related to HTHPs, including motivation, objectives, partners, and main results. Several ongoing research projects for HTHPs will receive federal funding during the next years. The ARAMIS[35] information system systematically records federal funded research, innovation, and evaluation projects.

Table 4-14: List of selected R&D projects for industrial HTHPs in Switzerland (Abbreviations of partners: CSD: CSD Ingenieurs, EAWAG: Swiss Federal Institute of Aquatic Science and Technology, EMPA: Swiss Federal Laboratories for Materials Science and Technology, EPFL: Ecole Polytechnique de Lausanne, ETHZ: ETH Zurich, HSLU: Lucerne University of Applied Sciences and Arts, FNHW: University of Applied Sciences and Arts Northwestern Switzerland, HEIG-VD: Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud, OST: Eastern Switzerland University of Applied Sciences, UNIGE: Université de Genève).

Project	Key information and output
SCCER EIP – Swiss Competence Center for Research in Energy, Efficiency of Industrial Processes (InnoSuisse, Swiss Innovation Agency, 2013-2020) www.sccer-eip.ch	**Motivation and objectives:** The SCCER EIP project, with 9 Swiss research institutions, developed the science and technology that allows Swiss industry to transition to sustainable use of energy in its processes, reduce greenhouse gases, and ensure that the target of 14 TWh energy consumption reduction until 2050 is achieved while keeping the impacts on the economics of the corresponding processes to a minimum. **Total Budget:** > 34 Mio. CHF **Partners:** ETHZ, EPFL, EAWAG, EMPA, HSLU, OST, FNHW, UNIGE **Key results:** Development of HTHP in laboratory-scale, test rigs are available at OST laboratory for further investigation of this technology, analysis of steam generation cycles using renewable energy, and investigation of electricity savings in refrigeration systems. **Output:** Experience in market analysis of HTHP systems, state-of-the-art in HTHP research, review papers, application case studies of industrial heat pumps, deep knowledge of the HTHP technology, and economic analysis.
IEA HPT TCP Annex 48 – Industrial Heat Pumps (Second Phase) (2017-2019) ARAMIS[36] Project No. SI/501782 www.heatpumpingtechnologies.org/annex48 and www.waermepumpe-	**Motivation and objectives:** The main goal was to overcome existing barriers to introducing industrial heat pumps to the larger scale market. Member countries participating and sharing knowledge were Germany (Operating Agent), Austria, Denmark, France, Japan, Switzerland, and the UK. **Partners:** EPFL, OST. **Key results:** Analysis and documentation of successful applications, case studies of industrial heat pumps, models for integrating heat pumps into processes, country-specific market overviews, and a white paper on the decarbonization of industrial heat by heat pumps. **Output:** Collection and experience of 25 case studies of industrial heat pumps in Switzerland, knowledge sharing in analysis and comparison of the different

[35] https://www.aramis.admin.ch/

[36] https://www.aramis.admin.ch/Grunddaten/?ProjectID=41721

izw.de	HP integration concepts, and international network of heat pump technologies.
Methods for developing integrated industrial heat pump systems considering existing and novel components, SFOE, 2016-2019) ARAMIS[37] Project No. SI/501487 Report Refrigerant Selection Tool	**Motivation and objectives:** This project explored new horizons for industrial heat pumps in industry and the participation in IEA Annex 48 regarding industrial HPs on behalf of Switzerland. In collaboration with SCCER-EIP, the goal was to develop new methods to improve industrial energy efficiency and mitigate CO_2 emissions by properly integrating industrial HPs and investigating the role of industrial heat towards the goals of the energy transition 2050. **Total budget:** 150 kCHF **Partners:** EPFL **Key results:** Innovative concepts of industrial HPs considering progress in working fluids, heat exchange, multistage systems, compression and expansion technologies using optimization methods and process integration techniques. **Output:** Methods for correctly placing heat pumps following a set of energetic principles based on Pinch Analysis methodology, saving potentials through heat recovery and HP integration in various Swiss industrial sectors, and web-based refrigeration selection tool.
SGHP – Steam-generating heat pump (InnoSuisse, 2020-2023)	**Motivation and objectives:** This national project develops a two-stage steam-generating heat pump (SGHP) system with open steam turbo compressor at the high stage. The major aim is the proof of technology for efficient steam generation from waste heat using a low-charge heat pump with hydrocarbon refrigerant and a mechanical vapor recompression unit with a direct drive oil-free turbo compressor. **Partners:** OST, EPFL **Key results:** A 100 kW SGHP prototype capable of operating up to 150 °C **Output:** Proof of technology and experience in the design and technology development of steam-generating heat pumps, deep knowledge of research status on SGHP technologies.
SWEET DeCarbCH – Decarbonization of Cooling and Heating in Switzerland (SFOE, 2021-2028) ARAMIS[38] Project No. SI/502260 www.sweet-decarb.ch	**Motivation and objectives:** The SWEET DeCarbCH project addresses the colossal challenge of decarbonizing heating and cooling in Switzerland within three decades and prepares the grounds for negative CO_2 emissions. 16 Swiss research institutions and 50+ industrial partners are participating. A major objective of the project is the combination of renewables, heat transformation, and storage for medium (80 to 200 °C) and high-temperature heating (>200 °C) as well as cooling. **Total Budget:** >16 Mio. CHF **Partners:** UNIGE, ETHZ, OST, HSLU, ZHAW, EMPA, Industrial partners **Key results:** System solutions for integrating renewables to deliver medium and high-temperature heat, increasing the share of renewable energy sources in existing solutions with digitalization approaches, and determining optimal integration levels. **Output:** Deep knowledge of the medium and high-temperature renewable heat, demonstration of heating technologies on the system level, experience evaluating the potential of negative emission technologies, and extended experience in knowledge and technology transfer (KTT).
IntSGHP – Integration of steam-generating heat pumps in industrial sites (retrofit) (SFOE, 2021-2023) ARAMIS[39] Project No. SI/502292	**Motivation and objectives:** This Swiss national project will investigate three specific case studies and analyze possible system integration of open and closed-cycle SGHPs. The aim is to fill the gap between the process integration analysis and implementation. The findings (control approach, storage, cost of equipment and integration, etc.) will derive guidelines applicable to many industrial sites in Switzerland and Europe. **Total budget:** 120 kCHF **Partners:** OST, Industrial partners **Key results:** Guideline with recommendations for retrofitting and integrating SGHPs, techno-economic comparison to current steam-generating systems

[37] https://www.aramis.admin.ch/Grunddaten/?ProjectID=38624
[38] https://www.aramis.admin.ch/Grunddaten/?ProjectID=48859
[39] https://www.aramis.admin.ch/Grunddaten/?ProjectID=49319

	(e.g., gas boiler), simulation model capable of doing a time-step analysis on these processes including integration of auxiliaries, storages, open and closed cycle SGHPs, and controls. **Output:** Experience in planning a demonstration project (P+D) and implementing SGHPs into industrial sites.
Case studies of industrial and high-temperature heat pumps (Swiss Federal Office of Energy, 2018-2022)	**Motivation and objectives:** This project investigates the technical and economic feasibility of heat pump integrations in the Swiss industry and thermal grids. They are matchmaking with manufacturers, distributors, contractors, etc. Results are usually confidential. **Partners:** OST, Industrial partners **Key results:** Direct collaboration and financing with various industries. In some cases, OST received a mandate from the SFOE to investigate heat pump integration, which can be published. **Output:** Experience in planning and integration of HTHP into industrial sites.
High-efficiency high-temperature heat pumps with temperature glide (Bridge Discovery, SNF, Swiss National Science Foundation, 2022-2025) SNF description[40] (Grant number 203645)	**Motivation and objectives:** This project investigates high-efficiency industrial HTHPs with temperature glide. Refrigerant mixtures will be optimized for typical industrial applications by an integrated refrigerant and process design framework. An experimental high-temperature test stand and a heat pump breadboard system will be developed to enable validation and demonstration. **Total Budget:** 1.5 Mio. CHF **Partners:** ETHZ, OST, Industrial partners **Key results:** Optimized refrigerants for temperature glides, high-temperature test stand (200 kW, 250 °C), and HTHP demonstrator. **Output:** Experience in handling refrigerant mixtures for HTHPs.
DeCarb-PUI – Decarbonization of industrial processes through redesign of the process-utility interface, SFOE, P+D project, 2021-2024) ARAMIS[41] Project No. SI/502298	**Motivation and objectives:** The overall aim of DeCarb-PUI is to decrease the exergy losses of the process-utility interface and consequently lower the exergy required for heating and cooling in process industries (e.g., steam systems). Case studies from the food and beverage sector are used to extend existing graphical tools and methods for heat integration and demonstrate the decarbonization potential thanks to larger heat recovery, enhanced efficiency, and profitability of heat upgrading technologies (heat pumps) and renewable resources. **Total Budget:** 230 kCHF **Partners:** HEIG-VD, HSLU, Industrial partners **Key results:** Demonstrating the improvement potentials (energy efficiency and decarbonization) when considering actual process requirements over the existing situation, demonstrating total cost reductions (CAPEX & OPEX of processes and utilities), elaborating practical guidelines and training material for industries and manufacturers. **Output:** Quantitative benefits (energy, CO_2 emissions, costs) over the state-of-the-art, a solution-focused collaboration between manufacturers and process industry partners, a practice-relevant methodology (graphical tools, e.g., GCC, methods, workflow), demonstration of case studies, increased awareness of all stakeholders.
HTHP-CH – Integration of HTHPs in Swiss Industrial Processes (2021-2025) ARAMIS[42] Project No. SI/502336 www.heatpumpingtechnologies.org/annex58	**Motivation and objectives:** 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 batch and continuous operation. Examples are drying, evaporation, sterilization, etc. Suitable HTHP integration concepts will be developed with quantified results regarding efficiency gains, CO2 emission reduction potentials, and cost efficiency. In parallel, the project will be accompanied by participating in the IEA HPT TCP Annex 58 on HTHPs to share results and knowledge with a group of international domain experts. Member countries participating and sharing knowledge (as of October 2021) are Denmark (Operating Agent), Austria, Belgium, Canada, France, Germany, Norway, Finland, Japan, China, the USA, and Switzerland.

[40] https://data.snf.ch/grants/grant/203645

[41] https://www.aramis.admin.ch/Grunddaten/?ProjectID=49367

[42] https://www.aramis.admin.ch/Grunddaten/?ProjectID=49514

	Total budget: 265 kCHF **Partners:** OST, HEIG-VD, EPFL, CSD, Industrial partners **Key results:** State-of-the-art HTHP technologies and ongoing developments for systems and components, strategies for converting to HTHP-based process heat supply, definition, and specifications for testing HTHPs. **Output:** Participation in the Annex project, extending international network on HTHP technologies, deep knowledge of commercially available HTHP technologies, and manufacturers ready for demonstration and research status.

4.13.7. Development perspectives for HTHP technologies in Switzerland

Switzerland's development perspectives for HTHP technologies are difficult to describe, as Switzerland is rather not a country producing and processing heat pump components. No specific targets are defined by a national institution, e.g., the number of HTHP installations, targeted installed capacity, or the number of technology providers.

The development perspectives relate to pilot and demonstration (P+D) projects and technology development. P+D projects act as an interface between research and the marketplace and promote the development and testing of new technologies (Figure 4-78). It is envisioned that some P+D projects on HTHP technology will be funded in the next 5 years, especially for heat pumps that produce steam.

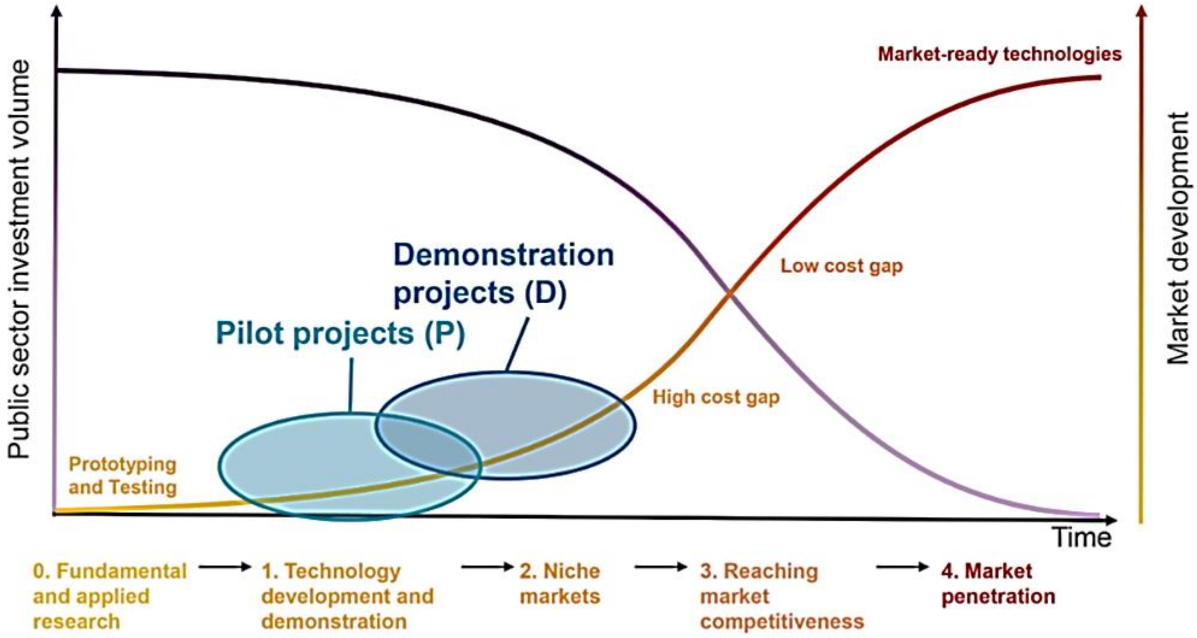

Figure 4-78: Characteristics of Pilot and Demonstration projects between research and market [135]

In addition, there is a need for case study analysis and techno-economic evaluation of HTHP integration, which will bring progress for HTHP integrations. The results of the case studies will be shared at international conferences and through the IEA Annex 58 project. Another topic is business models for the energy sector, which uses heat as a service. This energy contracting is a new sector for energy service companies.

An acceleration and control instrument for the decarbonization of the Swiss industry is the CO_2 tax on fossil fuels (e.g., heating oil and natural gas), which will be gradually increased over time and will be 120 CHF/tCO_2 from 2022 [136], which is relatively high compared to other European countries.

Finally, Figure 4-79 shows that the average ratio of electricity to gas prices for industrial companies in Switzerland is about 2.4, making electrically driven heat pumps relatively attractive compared to gas-fired boilers.

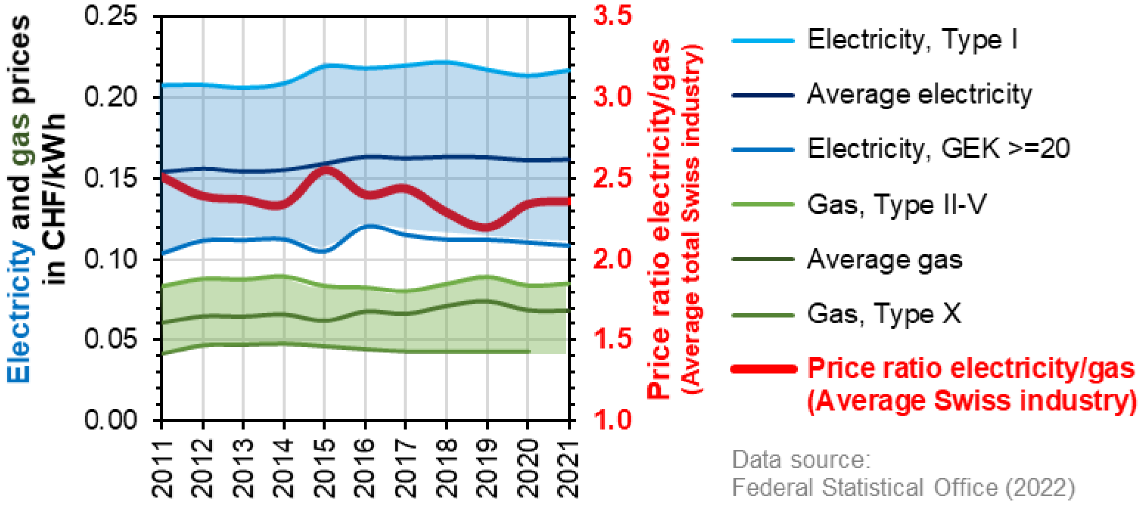

Figure 4-79: Electricity and gas prices for industrial companies in Switzerland (Data: Swiss Federal Statistical Office).

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