Technology Collaboration Programme
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Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Project 68

Industrial High-Temperature Heat Pumps

Task 1 – Technologies

Yearly report 2025

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Preface

This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), which is a Technology Collaboration Programme within the International Energy Agency, IEA.

The IEA
The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of nearly 40 Technology Collaboration Programmes.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)
The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the implementing agreement for a programme of research, development, demonstration and promotion of heat pumping technologies. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP, collaborative tasks, or “Projects”, in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. A Project is in general coordinated by one country which acts as the Project manager. Projects have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Project.
The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

Disclaimer
The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programmes or TCPs. The TCPs are organised under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.
This report has been produced within HPT Project 68. Views and findings in this report do not necessarily represent the views or policies of the HPT TCP and its individual member countries.

The Heat Pump Centre
A central role within the HPT TCP is played by the Heat Pump Centre (HPC).

Consistent with the overall objective of the HPT TCP, the HPC seeks to accelerate the implementation of heat pump technologies and thereby optimise the use of energy resources for the benefit of the environment. This is achieved by offering a worldwide information service to support all those who can play a part in the implementation of heat pumping technology including researchers, engineers, manufacturers, installers, equipment users, and energy policy makers in utilities, government offices and other organisations. Activities of the HPC include the production of a Magazine with an additional newsletter 3 times per year, the HPT TCP webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Projects, and this publication is one result of this activity.

For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
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Project manager

Project 68 about Industrial High-Temperature Heat Pumps is coordinated by the Project manager:

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The Project is being operated from 06/2025 to 05/2028 and is a follow-up to the former Annex 58 which will be referred to as Project 58 in this report, adopting the recently updated naming convention of the IEA HPT TCP.

The main information can be found at the Project 68 homepage:
https://heatpumpingtechnologies.org/project68/

Participating countries of Project 68

There is a high number of countries participating in Project 68, while each country is represented by a national team consisting of a number of organizations. The following countries are formally participating in Project:

- Austria
- Belgium
- Denmark
- Finland
- France
- Germany
- Japan
- Netherlands
- New Zealand
- Norway
- South Korea
- Spain
- Sweden
- Switzerland

A presentation of all national teams can be found on the Project 68 homepage.

Authors of the report and contributors to Task 1

The report has been prepared as a collaborative effort with contributions from various authors and has been coordinated by the main author Benjamin Zühlsdorf. An overview of the contributors is shown in Table 0-1.

Table 0-1: Overview of authors of the report, sorted by organization and country.

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Executive Summary

The decarbonisation of industrial process heating has become a key focus of industrial manufacturing companies in their journey towards sustainable production. Planning and realising the decarbonisation of process heating is a strategic activity that requires a sophisticated roadmap over several years. Such roadmaps should be based on structured, reliable and independent knowledge about the current and projected status of technologies and their perspectives. In this context, the IEA HPT Project 68 on industrial high-temperature heat pumps has conducted a review in the fall of 2025 of industrial heat pumps with heat supply temperatures above 100 °C, including both technologies and real-life projects with a minimum TRL of 4.

The Project has compiled technology descriptions from suppliers and an updated set of demonstration cases using a standardised template, including cycle type, working fluid, compressor, capacity, temperature ranges, indicative costs, TRL, and representative use-cases.

Three technological development trends have accelerated since the survey was first conducted under IEA HPT Project 58.

1) **The shift toward natural working fluids is pronounced.** The updated supplier analysis shows a larger portfolio share for water/steam and hydrocarbons than in Project 58 with carbon dioxide and absorption-systems maintaining steady roles (85 % natural working fluids up from 67 %). This development reflects regulatory pressure on F-gases, improved safety-by-design for A3/A2L systems, and competitive thermodynamic performance.

2) **Credible technology platforms reaching higher temperatures and larger capacities have emerged and progressed up the TRL scale.** More solutions are now positioned above 160 °C (32), including multi-stage steam compression and Stirling-type systems, while the 120 °C to 160 °C band has thickened with modularized offerings suited for replication (20). At scales of 10 MW and above, process-gas-derived centrifugal and steam-based platforms are advancing and benefit from economies of scale, which improve specific capital costs.

3) **Demonstration activity has risen sharply.** Many new or updated demonstration installations in industry fall in the 120 °C to 200 °C and 1 MW to 10 MW range, fulfilling a critical validation gap identified by Project 58. The upper boundary of reported supply temperatures has moved toward 300 °C, and the largest single installations reach 40 MW. This expanding evidence base is helping to de-risk procurement and operation for end-users.

Below 120 °C and up to about 10 MW, commercial solutions adapted from industrial refrigeration are widely available and often preferred on total cost and risk bases. Between 120 °C and 160 °C, solutions have moved from pilot (TRL 4-5) to routine demonstration (TRL 6-8) and are entering broader commercial availability as standard modules and mature systems (TRL 9). Above 160 °C, deployment remains demonstration-led, with early commercial adoption expected to enter service as reference plants soon. Above 10 MW, large centrifugal and steam compression platforms are advancing where site and network conditions favour centralised heat supply.

As these plants commission and share independently verified data, replication into industrial hubs and district heating systems should accelerate, supported by learning-curve cost reductions, standardised components and integrated systems, and service models that lower upfront risk. With lower, stable tariffs on electricity, effective carbon pricing, and targeted support for first-of-a-kind installations, HTHPs can contribute meaningfully to 2030 decarbonisation targets and establish a mature market foundation for rapid, widespread adoption with higher-temperature applications coming as the economical boundary conditions allow.

Nomenclature

Abbreviations

CAPEX	Capital Expenditure
CCHP	Closed Compression Heat Pump
COP	Coefficient of Performance
GHG	Green House Gas
HC	Hydrocarbon
HCFO	Hydrochlorofluoroolefin
HFC	Hydroflourocarbon
HFO	Hydrofluorooefin
HTHP	High Temperature Heat Pump
IEA	International Energy Agency
MVR	Mechanical Vapor Recompression
OPEX	Operational Expenditure
ORC	Organic Rankine Cycle
O&M	Operation & Maintenance
TCP	Technology Collaboration Program
TRL	Technology Readiness Level

Table of Content

1. Overview of Technologies

As part of the HTHP technology review, information about a wide range of different supplier technologies, both commercially available and under development, has been collected in two-page summaries. These descriptions can be found on the Project 68 homepage, please see the following link:
https://heatpumpingtechnologies.org/project68/task1/

In this chapter, the information collected in these summaries is analysed to give an overview of the current commercial state and developments (TRL 4-9 considered [2]) for high-temperature heat pumps.
The methods and assumptions made for analysing the trends are described in the methods section of the IEA HPT Project 58, Task 1 Report [1].

1.1. Overview of the collected information

The information was collected from the various suppliers in a standardised way using a common review template. The suppliers have provided all information without third-party validation. The information was provided as indicative capabilities and limits, which may differ to final installations because of application-specific parameters. Please note that a broad range of different HTHP technologies has been collected, and that some of the technologies indicate a TRL corresponding to a status of prototype demonstration, while a TRL of 9 can indicate a readiness level only valid for specific use cases.

The information collected about the technologies in general includes information about:

- System layout/type
- Compressor type
- Working fluid
- Capacity range
- Development status (TRL level)
- Operation hours achieved
- Maximum supply temperature or other limitations
- Expected lifetime
- Size
- Information on sub-components
- Range for specific investment cost for installed system without integration
- Performance data for use cases with $COP_{heating}$ and temperature glides on sink and source side
- Project examples

In total, information on 55 different HTHP technologies have been collected with 19 new technologies and 19 updated. Multiple efficiency examples from each are presented. An overview of the suppliers and key information is summarised in Table 1-2. The tabular results show a wide range of different technologies for HTHP from the various suppliers, and that the suppliers indicate highly varying TRL levels and costs, which depend on the given application and size of the heat pump. For several of the cases, the stated costs are estimates or cost targets to be achieved through future developments, especially for cases with low TRL. The newest version of the database with the descriptions are available on the webpage.

Table 1-1: Definition of TRL levels [2].

TRL 1	**Basic principles observed**
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	System prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Table 1-2: Overview of suppliers and HTHP technology, sorted alphabetically after supplier[1].

	Supplier	Compressor type	Working fluid	Capacity [MW]	Max supply temperature [°C]	TRL	From Project 58, Apr. 2025
<120 °C	Dutek (HT heat pump)	Reciprocating, screw	R600a	0.025-1.2	110	9	
	Johnson Controls – Sabroe (HyePAC)	Piston	R717/R718	0.5-2.1	110	9	
	Mayekawa (Eco Circuit 100)	Reciprocating	R1234ze(E)	0.1	100	8-9	●
<140 °C	COMBITHERM	Screw	R1233zd	0.3-3.3	120	9	●
	Dutek (XT heat pump)	Screw	R600	0.5-3	130	9	
	Fuji Electric	Reciprocating	R245fa	0.03-0.3	120	9	●
	GEA (CO_2 heat pump)	Reciprocating	R744	0.1-6	130	9	
	Johnson Controls – Sabroe (HitemHP)	Reciprocating	R600, R600a	0.3-1	125	9	
	KOBELCO (SGH120)	Screw	R245fa	0.37-1.85	120	9	●
	Mayekawa (Eco Sirocco)	Reciprocating	R744	0.1	120	9	●
	MHI Thermal Systems	Turbo compressor (centrifugal)	R134a	0.627	130	9	●
	Ochsner	Screw	R1233zd	0.5	130	9	●
	HECK Kältetechnik	Piston, screw	HFOs, HFCs	0.025-1.5	120	7	
	Mayekawa Europe (HS-compressor)	Piston	R600	0.75	120	7	●
	Taeyang Electric	Turbo compressor (centrifugal)	R245fa	0.3-0.35	120	7	
	THERMODRAFT	Screw with vapor injection	HFOs, HFCs	0.1-1.5	125	7	
	AF Energy	Reciprocating, screw	R1234ze(E), R1233zd	0.02	120	6	
	Emerson	Reciprocating + Reciprocating	R245fa, R410a	0.03	120	6	●
<160 °C	Everllence (CO_2 heat pump)	Turbo compressor (centrifugal)	R744	10-50	150	9	●
	Tocircle Industries (MVR1000)	Rotary positive displacement	R718	0.4-2.5	153	7	
	Pars Makina	Rotary double-hinged arc vane compressor	R1233zd(E)	0.025-0.125	150	6	
	RANK	Screw	HFOs	>0.5	150	6-9	
	Mayekawa Europe (FC-compressor)	Screw	R601	1	145	5	●
<200 °C	Solid Energy	Screw	Hydrocarbons	>0.2	165	9	
	AGO Energie & Anlagen	Piston, screw	R717/R718	1-10	160	8-9	
	Aneo Industry	Piston, screw (R717); screw, turbo (R718)	R717, R718	1-5	190	8-9	
	AtmosZero	Turbocompressor (centrifugal)	R1234ze(E), R515B, R1233zd(E)	<1	185	8	
	GEA (Ammonia steam generator)	Piston, screw (R717); screw, turbo (R718)	R717, R718	1.2-10	175	8-9	
	SPH Sustainable Process Heat	Piston	Hydrocarbons, HFOs	0.3-2.5	180	8-9	
	Tocircle Industries (MVR400)	Rotary positive displacement	R718	0.4-2.5	180	7	
	SRM	Screw	R718	1-4	165	6	
	WSE-Turbo	Turbo compressor (centrifugal)	R718	0.5-5	195	4-6	

[1] Mixtures are referred to with a "/" (example: R717/R718); possibility for different working fluids is referred to with a "," (example: R600, R600a)

	Upheat	Turbo compressor (centrifugal)	R601, R601a	1-4	180	3	
	TLT-Turbo	Turbo (centrifugal)	R718, process vapours	<5	180	n/a	
≥200 °C	EPCON		R718, process fluids	0.2-100	210	9	
	Heaten	Piston	Hydrocarbons, HFOs	0.8-50	200	9	
	KOBELCO (MSRC160L)	Screw	R718	0.8	n/a	9	●
	KOBELCO (SGH165)	Screw + Screw	R245fa/R134, R718	0.624	175	9	●
	Olvondo	Piston	R704	2.3	200	9	
	Qpinch	-	R718, H3PO4 and derivatives	2	210	9	
	Spilling	Piston	R718	1-15	250	9	●
	Turboden	Turbo compressor (centrifugal)	R600a, R245fa, R1233zd, R718	5-40	250	9	●
	Enerin	Piston	R704	0.3-10	250	8	●
	Lübbers Anlagen- und Umwelttechnik	Turbo compressor, piston	R718	1.5-50	250	8-9	
	Piller	Turbo compressor (centrifugal)	R718, vapors	>1	230	8-9	●
	ecop Technologies	Centrifugal compression	Ecop fluid 1	0.7	200	7-8	
	Heatlift	Turbo compressor (centrifugal)	R1233zd(E), R718, R600, cyclopentane	>2	230	7-8	
	Skyven	Screw, turbo (centrifugal)	R718	<73	215	7-8	
	Everllence (High Temp VCC)	Turbo compressor (centrifugal)	R290, R717, R600, R134a, R1233zd	10-100	300	6-9	●
	Futraheat	Turbo compressor (centrifugal)	R1233zd	0.3-1.5	200	6	●
	Karman Industries	Turbo compressor (centrifugal)	R718, ethanol, mixed vapours	1-20	300	6	
	Standard Fasel	Screw, piston, turbo	R718, R717	1-10	200	6-9	
	Airthium	Piston	R704, R728	0.1-5	250	4	
	SynchroStor	Piston	R744, R728, argon	0.5-1.5	250	4-6	
	TTI	Turbo compressor	R718, air	Dependent on application	Dependent on application	n/a	

1.2. Overview of key aspects

This section outlines examines the trends from the collected technology description. We relate maximum supply temperature to capacity, assess specific investment cost against mean temperature lift, maximum supply temperature, and capacity, examine heating COP and Lorenz efficiency versus mean temperature lift, and summarize expected equipment lifetimes by capacity range.

1.2.1. Working fluid

A comparison in terms of distribution of the reviewed technologies among different working fluid types is presented in Table 1-3 for both Project 68 and Project 58. An increasing proportion of technologies relies on natural working fluids, which now contributes to almost half of all the reviewed technologies in Project 68. Among all the technology suppliers, 15 suppliers offer solutions exclusively based on synthetic working fluids, while the remaining 6 suppliers have both hydrocarbon-based and synthetic working fluid-based heat pumps in their portfolio. The largest growth is observed for hydrocarbons and water, supported both by increasing trends in pushing the limit of maximum supply temperature for compressors and by the development of cascade cycles based on a hydrocarbon bottom cycle and a steam compression system as a top cycle. An increasing number of manufacturers (4 increasing from 1) also states the possibility of using process vapours as working media through compression technology, reflecting the interest in coupling directly the heat pump with the manufacturing process, thus removing the heat exchanger required for working fluid evaporation. In addition, some of the compressor manufacturers have declared the possibility of using air as working medium.

Table 1-3: Number of suppliers offering at least one technology per working fluid type.

	Working fluids	Updated review in Project 68, Nov. 2025		Initial review in Project 58, Apr. 2025	
Natural	CO_2 (R744)	4	7%	4	10%
	Water (R718)	18	33%	12	29%
	Ammonia (R717)	6	11%	4	10%
	Hydrocarbons	13	24%	7	17%
	Helium (R704)	3	5%	2	5%
	Air	3	5%	0	0%
	Process fluids	4	7%	1	2%
	HFOs, HFCs	21	38%	19	45%
	Natural	**47**	**85%**	**29**	**67%**
	Synthetic	**21**	**38%**	**19**	**44%**

Figure 1-1 shows the ranges of maximum supply temperatures and thermal capacities for the most common working fluids. The biggest limitations to the maximum supply temperature are encountered by hydrocarbons, ammonia (absorption cycles and hybrid absorption-compression cycles) and synthetic working fluids (HFOs and HFCs). In fact, these working fluids, historically operated in subcritical conditions, are limited in the operating temperatures by the relatively low critical temperatures and by their use in combination with screw compressors, which are typically characterized by limited maximum supply temperatures with respect to other compressor types (Section 1.2.2). For these reasons, an increasing interest in cascade systems, using steam in the top cycle is observed. Technologies employing all working fluid types can be found for capacities around 1 MW, while capacities above 10 MW are available only with water and CO_2 as working media. This is related to the commercial availability of centrifugal compressors for these working fluids, since turbo compressors are the only technology able to reach capacities above 10 MW per unit.

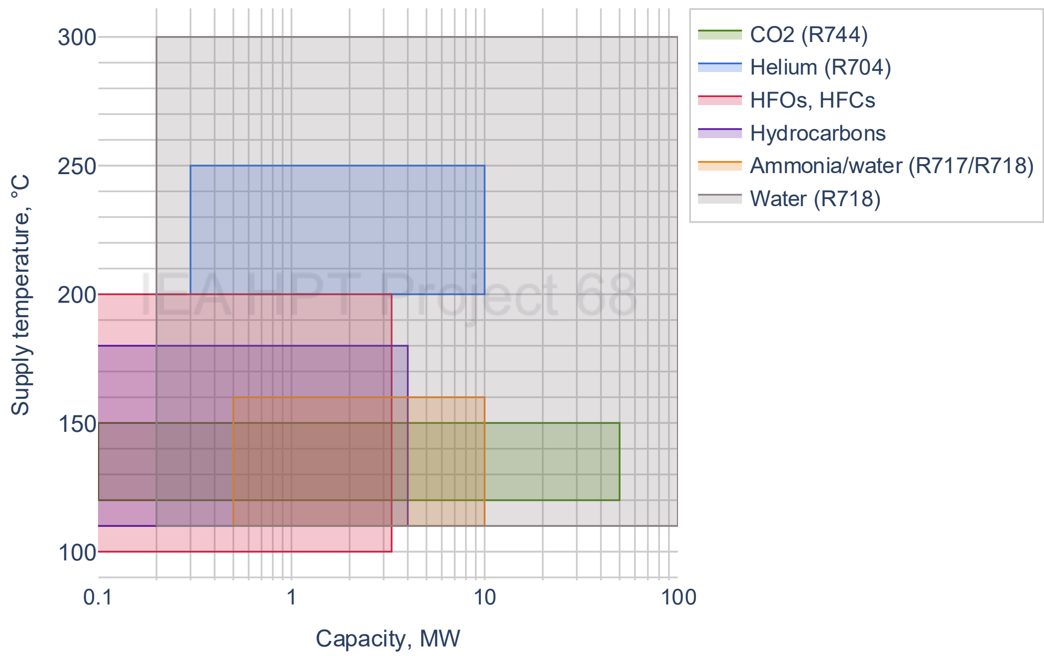

Figure 1-1: Maximum supply temperature range and capacity range per working fluid type[2].

1.2.2. Compressor

As mentioned in section 0, compressors have a key role in constraining the maximum supply temperature and the capacity of the heat pump. Table 1-4 reports the number of technologies per compressor type for the current review (Project 68) and the previous one (Project 58). Screw compressors have seen the highest growth in relative numbers,

[2] The capacity reported by technology suppliers may refer to the combination of several heat pump modules. Ammonia/water as working fluid refers both to absorption cycles and absorption cycles with compressors.

followed by turbo compressors. This trend can be related to the increasing number of hydrocarbon heat pumps under development or commercially available. Overall, it can also be observed that heat pump suppliers have expanded their portfolio with additional compressor types, and the compressors have been adapted to be employed with multiple working fluids.

Figure 1-2 shows the range of maximum supply temperature and of thermal capacity for different compressor types. Supply temperatures above 160 °C can be reached only by oil-free piston compressors and turbo compressors, which are also the technologies available at capacities above 10 MW.

Table 1-4: Number of technologies per compressor type.

Compressor type	Updated review in Project 68, Nov. 2025	Initial review in Project 58, Apr. 2025
Piston	24	18
Screw	19	9
Turbocompressor	19	13
Other	1	2

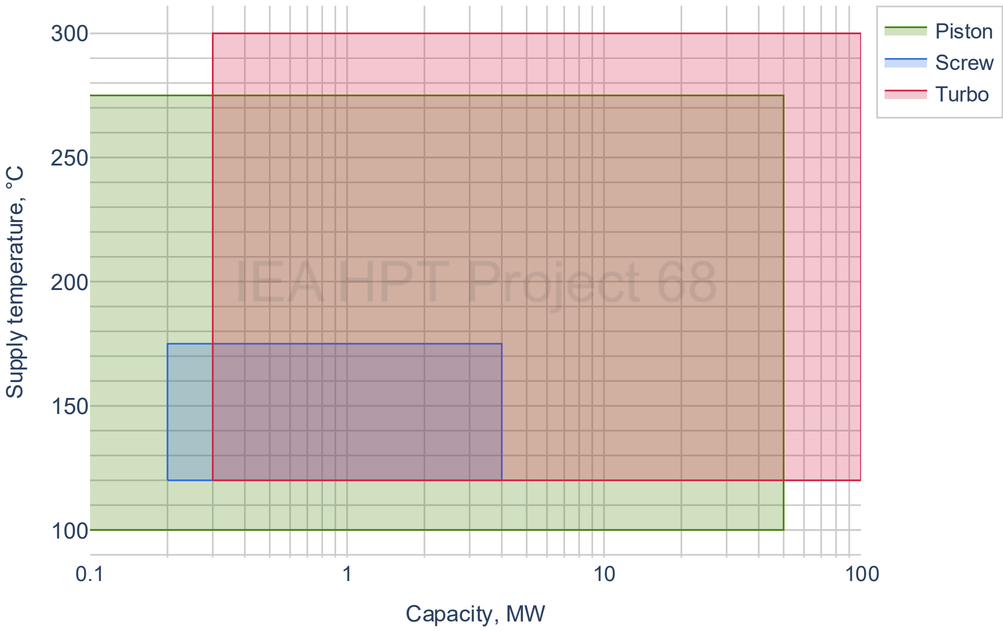

Figure 1-2: Max supply temperature and capacity range per compressor type[3].

1.3. Overall trends between key parameters

Based on the collected information, a series of calculations and plots summarise the collected information and show the overall trends between the key parameters of the different technologies (for electrically driven cycles).

Figure 1-3 shows a clear positive correlation between capacity and feasible supply temperature: larger systems tend to reach higher maximum temperatures. Below about 500 kW, the curve is essentially flat, indicating limited supply temperature in small units irrespective of supplier or cycle choice. This also represents a possible gap where new development projects and suppliers may find differentiation from current directions. In contrast to Project 58, many HTHPs collected in Project 68 cluster in the 1–10 MW range, where two prominent groups appear: a dense band between 160 °C and 200 °C, reflecting the maturing and growing availability of multi-MW platforms capable of mid-to-high temperature supply, and a second group around 125 °C, representing standardised modules adapted from industrial refrigeration.

[3] The capacity reported by technology suppliers may refer to the combination of several heat pump modules.

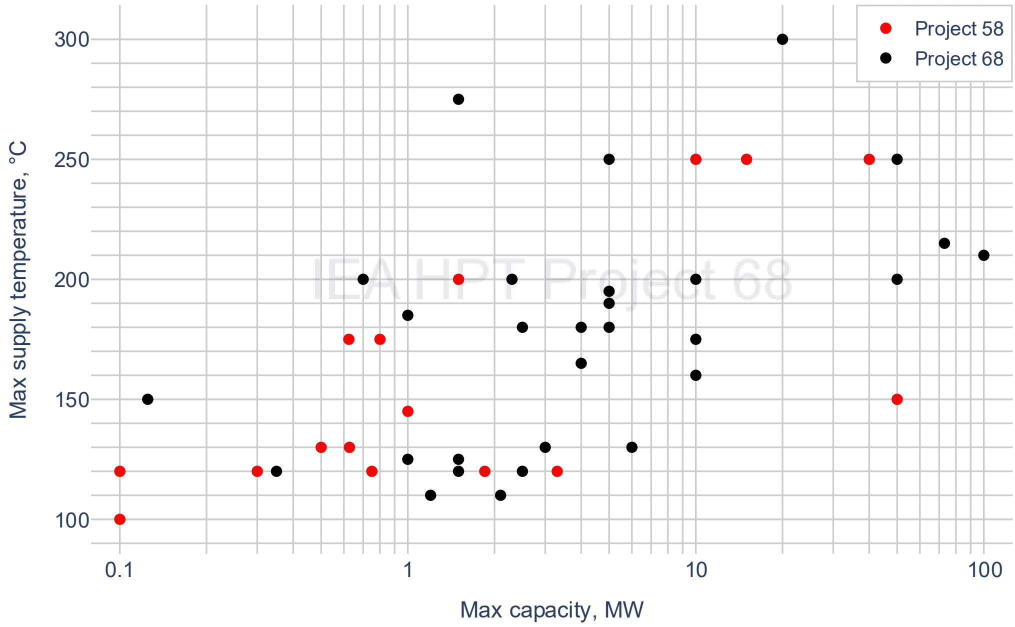

Figure 1-3: Maximum supply temperature as a function of maximum capacity.

In Figure 1-4, there is no clear correlation between specific investment cost and mean temperature lift. Reported unit costs span roughly 300 €/kW to1200 €/kW, with substantial overlap between lifts. This spread reflects differing compressor platforms, working fluids, and degrees of product maturity, as well as application-specific design choices (e.g., approach temperatures, HEX materials, safety concept) that mask any simple temperature-lift-to-cost relationship at this level of aggregation.

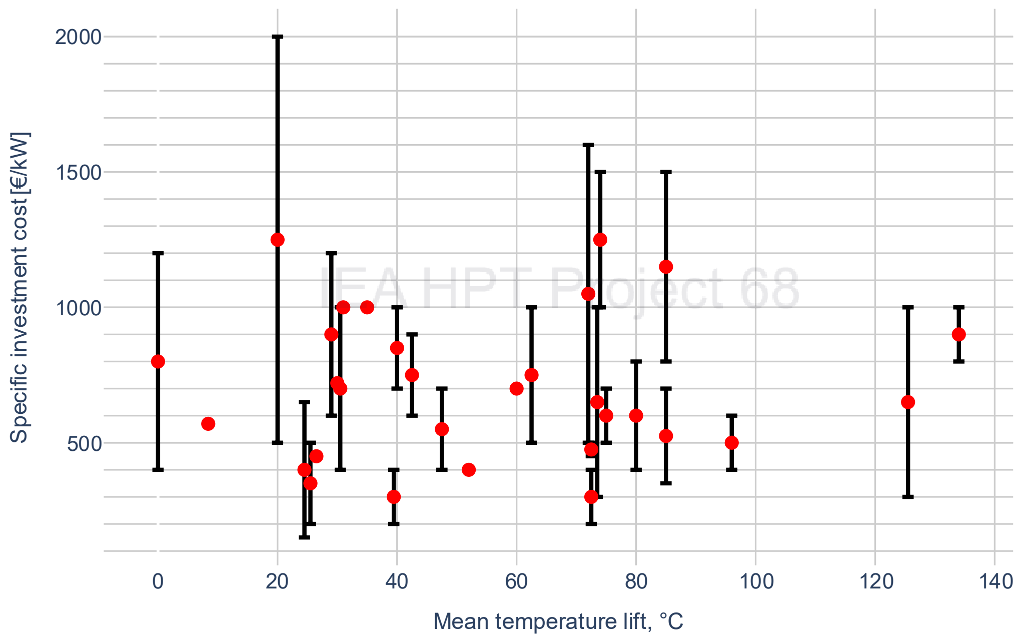

Figure 1-4: Specific investment cost[4] as a function of mean temperature lift.

Vague pattern of technology maturity emerges when costs are viewed against maximum supply temperature in Figure 1-5. Technologies clustered between 110 °C and 150 °C form a lower-cost group with relatively small variance - consistent with greater commercial maturity, standardised modules, and fewer unknowns in engineering and

[4] The specific investment cost is considered per unit and does not include planning and integration costs.

equipment supply chains. Above 160 °C, higher-grade material demands, compressor staging, and tighter operating envelopes contribute to both higher and more uncertain costs, as indicated by the greater scatter. Above 220 °C the trend becomes less clear potentially due to the fewer data points.

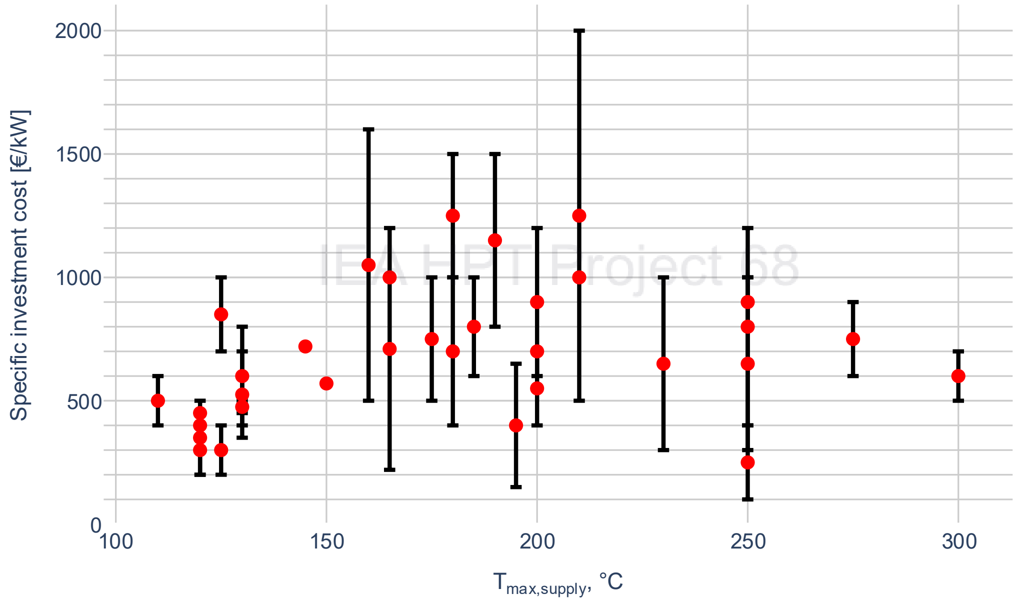

Figure 1-5: Specific investment cost[5] as a function of maximum supply temperature. The investment cost is for the unit cost without any integration.

The investment cost cluster around 500 €/kW on average for products between 500 kW and 2 MW, reflecting today's serially produced modules (Figure 1-6). Around 3 MW there is a uptick in the variance of the cost, likely attributable to bespoke engineering, non-standard packages, and site-specific constraints.

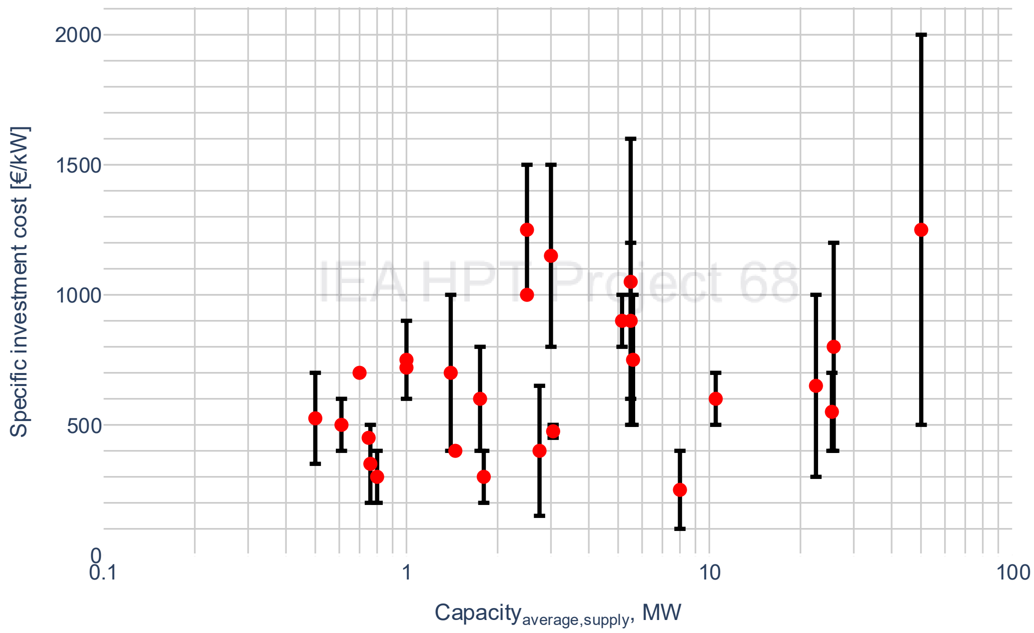

Figure 1-6: Specific investment cost as a function of average capacity.

[5] The specific investment cost is considered per unit and does not include integration costs.

At larger scales, cost trend down again but with large variance, reaching 500 €/kW to 700 €/kW around 25 MW, which points to economies of scale for large single-unit centrifugal/steam platforms and shared balance-of-plant. Overall, the curve suggests two efficiency regimes: (i) standardized 500 kW to 3 MW classes benefitting from large production volumes, and (ii) very large units benefitting from scale, with a transitional zone where custom design temporarily lifts specific CAPEX.

Figure 1-7 and Figure 1-8 plot heating COP and Lorenz efficiency as functions of mean temperature lift[6]. The calculated Lorenz efficiency assumes that the sink and source temperature profiles are linear. The indicated heating COP spans 1.4–10.3, with the legend distinguishing cases with crossing source/sink profiles and MVR cases.

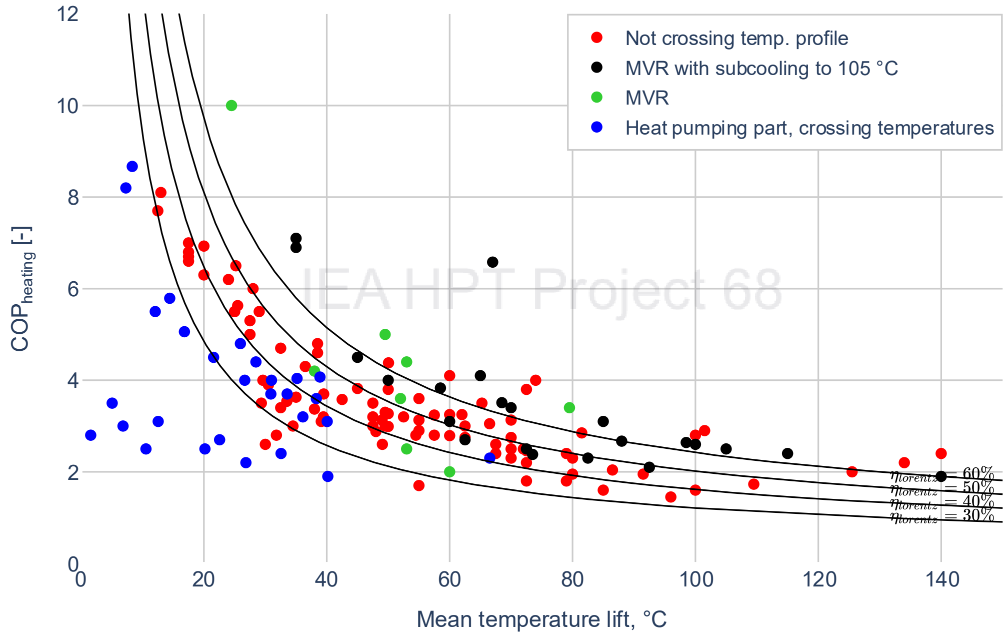

Figure 1-7: COP$_{heating}$ as a function of mean temperature lift. The constant Lorenz efficiency curves are generated based on a source logarithmic mean temperature of 30 °C.

Reference lines for ideal cycles at different Lorenz efficiencies are shown for context based on a source logarithmic mean temperature of 30 °C. As expected from the Lorenz COP, COP heating declines with increasing mean temperature lift. Cases with crossing temperature profiles (where the sink and source can directly exchange heat) systematically exhibit lower heating COP than non-crossing cases because only the non-crossing part is considered. MVR cases show comparatively high heating COP. The MVR systems which take the heat load from subcooling the steam into account (black dots) generally perform similar as the other MVR systems (green) with an outlier at a mean temperature lift of 65 °C However, a performance reduction would be expected in closed loop implementations due to heat exchanger losses between the working fluid and process streams essentially increasing the temperature lift.

[6] See Section 1.1 of “IEA HPT Project 58, Task 1 Report – B. Zühlsdorf et al. 2023” for terminology, including the “heat-pumping part” for crossing temperature profiles.

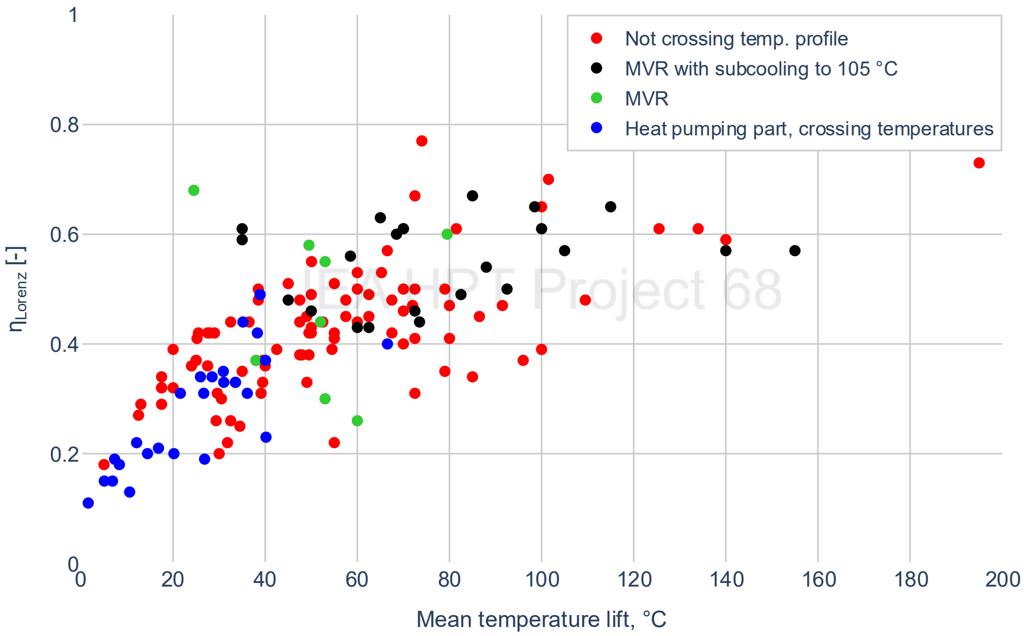

Figure 1-8: Lorenz efficiency as a function of the mean temperature lift.

The Lorenz efficiency ranges from 0.2 to 0.78 and shows a clear positive dependence on lift. Lorenz efficiencies are also higher where the cycle design and working fluid choice dictate that heat exchange are better matched to the process. This effect becomes becomes less important for higher lifts, as the losses during compression become increasingly important. Crossing profiles lowers efficiency relative to non-crossing cases. A second factor to the COP is the choice of more or less efficient components. Overall, the trends are consistent: larger mean lifts drive down achievable COP following thermodynamics, and integration quality (matching working fluid choice and system design to the process) is the principal lever for attaining a higher Lorenz efficiency. One outlier has a Lorenz efficiency of 1.06 based on the simplified method due to the system delivering superheated steam, which is not represented well by the assumption of linear temperature profiles.

Figure 1-9 depicts expected equipment lifetime by capacity range. Across all technologies, the stated averages cluster around 20 years, with a wider variance at smaller capacities and tighter convergence as capacity increases. Every technology reports an average lifetime above 10 years, and the longest indicated value is 30 years. This pattern is consistent with field experience: smaller units span a broader mix of duty cycles, environments, and designs, while larger multi-MW platforms benefit from heavier-duty components, more engineering, and established maintenance regimes.

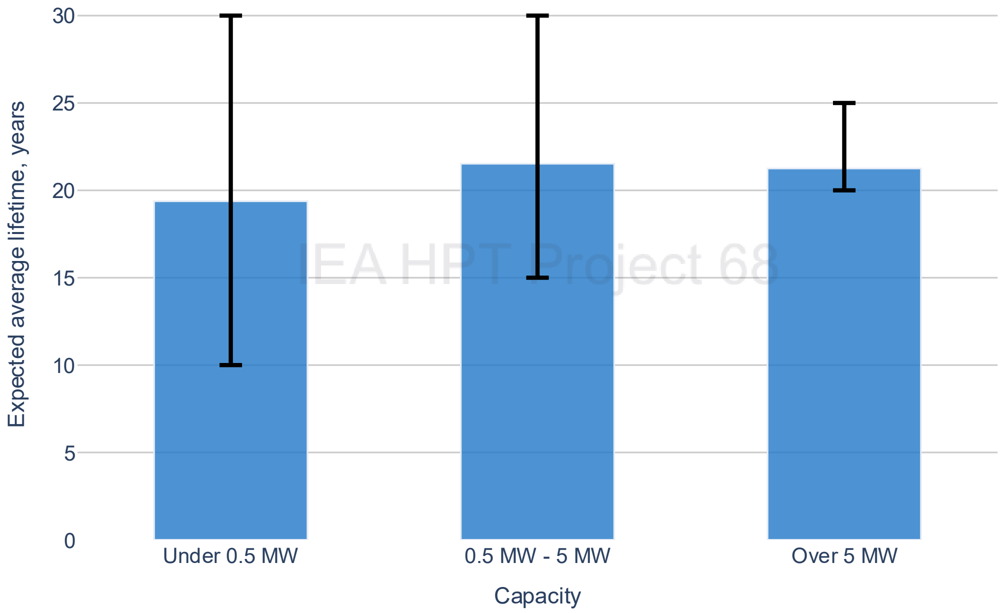

Figure 1-9: Average expected lifetime as a function of capacity.

2. Overview of Demonstrations

As part of the HTHP technology review, information about several demonstration cases was collected in collaboration with the heat pump manufacturers. The demonstration case database includes both running and planned demonstration projects, the latter of which are expected to be commissioned within three years.. Information about the ongoing demonstration cases has been collected in two-page summaries, which can be found on the Project 68 homepage at the following link:
https://heatpumpingtechnologies.org/project68/task1/

2.1. Overview of the collected information

Overall, new or updated information 40 demonstration cases has been collected and included in the Project 68 database. 11 of them where presented in Project 58 in their current state. An overview of the demonstration cases and key information is summarized in Table 2-1 on the next pages.

Table 2-1: Overview of demonstration cases and their characteristics[7].

Supplier	Sector (Process)	Source in → out [°C]	Source type	Sink in → out [°C]	Sink type	Working fluid	Compressor type	Capacity [MW]	COP	From Project 58, Apr. 2025
Mayekawa Europe	Food and beverage, feed (Shrimp processing)	12 → 7	Ammonia	140 → 145	Steam (4 bar)	R717, R601	Screw + Screw	0.8	1.8	
Everllence	District heating	29 → 3	Water	→ 200	Steam (15 bar)	Natural	Centrifugal	40	>2	
Aneo Industry	Food and beverage, feed (Protein/fish oil production)	80 / 98 → 35 / 98	Water / steam (saturated)	→ 148	Steam (4.5 bar)	R717, R718	Piston, centrifugal	4.4	3.5–6.5	
GEA	Food and beverage, feed (Dairy, spray drying)	5 → 3	Water	35 → 130	Water	R744	Piston	0.85	2.5	
SPH Sustainable Process Heat	Materials (Tobacco drying)	50 → 36	Water	90 → 139	Steam (3.5 bar)	R515B, R1233zd	Reciprocating	0.65	2.5	
Turboden	District heating	70 → 60	Water	60 → 120	Water	R1233zd (E)	Centrifugal	6	5–8	
RANK	District heating	25 → 15	Water	60 → 90 / 105 / 130	Water	R1234ze (E), R1233zd (E)	Screw	1	2.78	
AGO Energie & Anlagen	District heating	23 →	Water	120 →	Water	R717, R718	Piston	1.8	2.6	
AGO Energie & Anlagen	Food and beverage, feed (Brewing)	90 →	Water	120 →	Water	R717, R718	Piston	1.23	6.1	
Heaten	Food and beverage, feed (Sugar production)	102 → 100	Steam (saturated)	128 → 130	Steam (saturated)	R1233zd (E)	Piston	4	6	
Olvondo	Food and beverage, feed (Dairy)	85 / 31 → 75 / 26	Water / water	105 → 155	Steam (5 bar)	R704	Piston	5.4	2	
AtmosZero	Food and beverage, feed	-20 → 40	Air	→ 165	Steam (7 bar)	R513a/R1233zd(E)	Centrifugal	0.65	1.3–2.04	
ThermoDraft	Marine	75-85 → 65-75	Water	90-100 → 110-120	Water	R1233zd (E)	Screw	0.12	3.4–5.6	
SPH Sustainable Process Heat	Materials (Metal treatment)	92 → 84	Water	90 → 159	Steam (6 bar)	R1336mzz(Z)	Piston	1	2.5	
Turboden	Pulp and paper	17 → 8	Water	104 → 170	Steam (superh	R600a	Centrifugal	12	2	

7 → : from source to sink temperature; /: when multiple source or sink temperature levels are present. The cases where just inlet or outlet temperature is given for the sink or the source may refer either to unknown temperatures or compression systems where the source inlet temperature refers to the compressor inlet temperature and the sink outlet temperature refers to the compressor outlet temperature.

					eated)					
Aneo Industry	Food and beverage, feed (Thermal pelleting)	60 → 30	Humid air	4 → 75 / 140	Water / steam (2 bar)	R717, R718	Screw, piston, centrifugal	1.68	3.1	
Celeroton	Chemicals and refinery (Methanol distillation)	75 →	Methanol/water mixture	→ 157	Methanol/water mixture	Methanol/water mixture	Turbo	-	-	
Psycotherm, Heaten	Materials; pulp and paper (Roof tiles production)	85 / 60 → 70 / 50	Air / humid air	230 / 125 → 300 / 225	Air / steam (5 bar)	Air, R600a, R718	Piston, turbo	1	1.5/ 2.1	
HTT	Food and beverage, feed; pulp and paper; materials	90 / 150 → 70 / 130	Water	→ 265 / 200	Oil / water	Air	Turbo	0.6	1.5–1.8	
TTI	Food and beverage, feed (Frying)	95 →	Process gas	150 → 170	Oil	R718	Turbo	1	3	
SPH / Spilling	Pharmaceuticals	70 →	Water	→ 184	Steam (11 bar)	R600, R718	Piston	1.7	4.4	
GEA	District heating	50 → 40	Water	70 → 80	Water	R717	Piston	5.2	5–6	
BS NOVA	Pulp and paper	90 → 80	Water	→ 162	Steam (6.5 bar)	LiBr-H2O	Absorption + TVR[8]	0.34	0.48 [9]	
Cannon Bono	Pulp and paper	90 → 80	Water	105 → 162	Steam (6.5 bar)	R1233zd (E)	Screw	0.6	5.2	
SPH Sustainable Process Heat	Pulp and paper	46 → 41	Water	90 → 123	Steam	R515B, R1233zd	Screw, piston	1.2	2.3	
GEA	Food and beverage, feed (Sugar refining)	75 → 75	Steam	110 → 140	Steam	R601	Screw	4	3–5	
AMT Kältetechnik	Food and beverage, feed (Drying)	76 → 72	Water	96 → 138	Water	R1336mzz(Z)	Screw	0.374	3.2	
AMT Kältetechnik	Materials (Brick drying)	88 → 84	Water	96 → 121	Water	R1336mzz(Z)	Piston	0.296	5	
Olvondo	Pharmaceutical	36 → 34	Water	105 → 183	Steam (10 bar)	R704	Piston	2.3	1.7	
Ochsner Energie Technik	Materials (Leather production)	55 → 50	Water	100 → 110	Water	R1233zd	Screw	0.338	3.2	•
Qpinch	Chemicals and refinery(Ethylene polymerization)	135 → 80	Steam, water	140 → 185	Steam (saturated)	R718/H3PO4	TVR[10]	2.9	0.45	•
Oilon/ Astatine	Food and beverage, feed (Whiskey distillation)	60 →	Water	→ 115	Water	High temp refrigerant	Piston	1	5	•
Skala Fabrikk	Food and beverage, feed (Dairy)	5 / 20 → 0 / 12	Ice water / water+glycole	95 → 115	Water	R290, R600	Piston	0.3	2.5–3.4	•
Spilling	Chemicals	152 →	Steam (5 bar)	→ 240	Steam (19.5 bar)	R718	Piston	12	5.3–5.8	•
Spilling	Pulp and paper (Drying)	133 →	Steam (3.2 bar)	133 → 240	Steam (16 bar)	R718	Piston	11.2	4.2–4.7	•
Piller Blowers & Compressors	Materials (EPDM rubber, stripper)	92 → 60	N-hexane / water	→ 126-131	Steam	R718	Turbocompressor	10	4.4	•
MHI Thermal Systems	Materials (Transformer coil drying)	55 → 50	Water	70 → 130	Water	R134a	Centrifugal	0.627	3	•

[8] Thermal Vapor Recompression
[9] Thermal COP (Electrical COP>25)
[10] Thermal Vapor Recompression

Kobelco	Waste water treatment (Sewage sludge drying)	93 →	Steam (saturated)	→ 160	Steam (saturated)	R718	Roots, screw	0.675	2.9	•
Kobelco	Chemicals (Bioethanol distillation)	65 → 60	Water	20 → 110-120	Steam (saturated)	R245fa	Screw	0.37	3.5	•
Epcon/ Rotrex	Waste water treatment (Sludge/waste drying)	100 →	Steam (saturated)	→ 125-146	Steam (saturated)	R718	Turbo	0.5	4.5–8.7	•

2.2. Overview of key aspects

An overview of the distribution among different sectors where HTHPs are employed for the collected demonstration cases is shown in Figure 2-1. The food and beverages sector (including feed) and the pulp and paper sector dominate the picture, with almost half of the cases falling into these categories. District heating networks operating at high temperatures and chemical processes still constitute a good portion of the collected cases, while new sectors for HTHP applications are turning up, such as steel manufacturing and marine applications.

The collected data show that new demonstration cases use primarily synthetic working fluids and water as working fluids, with only few hydrocarbon systems commissioned or planned. This is in contrast with the collected data on technology suppliers, where few synthetic working fluid-based technologies are reported and a significant growth in hydrocarbon systems is observed.

In terms of the compressor type, piston and centrifugal compressors are found to be the most commonly used for the newly collected demonstration projects. This trend can be seen as a result of the growing capacities and supply temperatures, as discussed in section 2.3.

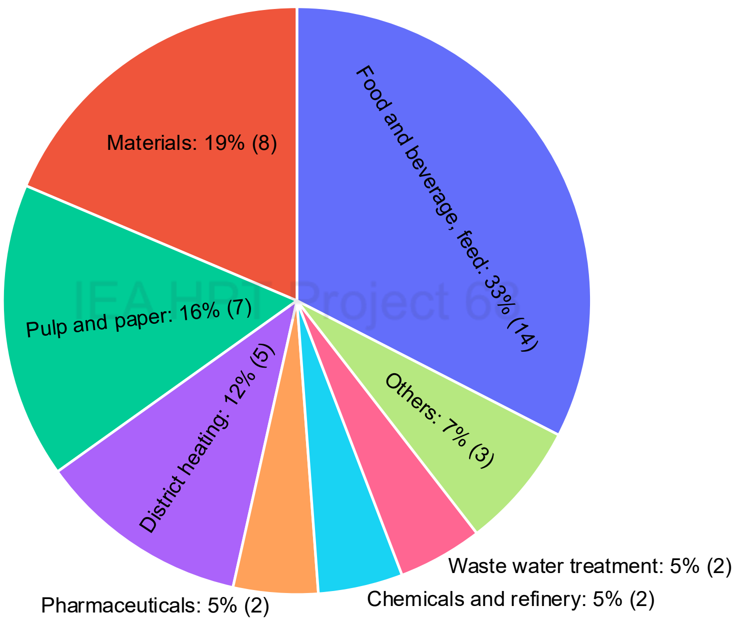

Figure 2-1: Distribution of demonstration cases among sectors in % and number of cases.

2.3. Overall trends between key parameters

The relation between the key parameters of the demonstration cases collected, namely thermal capacity and maximum supply temperature, is shown in Figure 2-2 for the new or updated cases collected within Project 68 and the cases collected in Project 58. Overall, a substantial portion of new cases lies in the 120 °C to 200 °C supply temperature and 1 MW to 10 MW capacity region, where very few cases where previously observed in the Project 58 review. The boundary of maximum temperature supply has also increased from 240 °C to 300 °C, while the largest system has shifted from 11 MW to 40 MW.

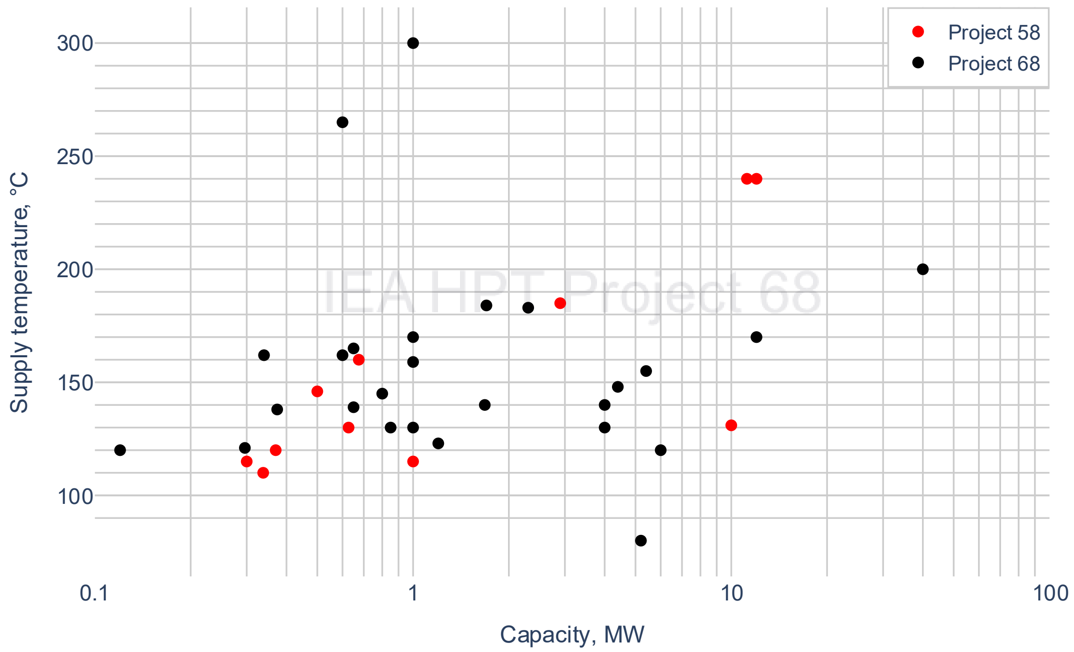

Figure 2-2: Supply temperature as a function of capacity.

3. Technology development and deployment perspectives

During the recent years, three trends have emerged: natural working fluids are growing faster than synthetics; proven heat pump components that handle higher temperatures and larger capacities are now on the market; and the number of real-life installations is turning a corner and beginning to take off, especially from 120 °C to 200 °C, for capacities between 1 MW and 10 MW. Together, these shifts move HTHPs from the development pipeline to a mainstream technology in the 120 °C – 160 °C range and set the stage for projects providing heat above 160 °C.

3.1. Working fluids: Natural options are growing faster than synthetics

Project 58 already observed that most developments were trending toward natural working fluids, with only a limited number of manufacturers focusing exclusively on HFOs. The analysis of the updated HTHP supplier database shows that the shift has continued. Natural working fluids is now an option for 72 % of the reported technologies, up from 58 % in Project 58. The majority of new product lines use natural fluids. Water/steam and hydrocarbons have posted the largest gains, while CO_2 and ammonia absorption systems maintain a steady presence. This development is consistent with regulatory headwinds for F-gases, growing safety-by-design maturity for A3/A2L systems, and competitive thermodynamic performance at target lifts.
The reasons are threefold. Steam and CO_2 centrifugal platforms increasingly address high-temperature and large-capacity applications above about 150 °C and 10 MW. More suppliers now standardize cascades that pair a hydrocarbon bottom cycle with a steam compression top cycle, which keeps working fluid temperatures within safe envelopes while pushing overall supply temperatures higher. Finally, natural fluids provide a hedge against policy risk and long-term supply uncertainty without compromising performance.

Bottom line: The natural working fluid share is larger and growing faster than synthetics, and cascade systems using water/steam and hydrocarbons for 120 °C to above 200 °C are becoming available, with CO_2, helium and air remaining niche applications.

3.2. Technologies at higher temperatures and larger capacities are emerging and consolidating

Project 58 outlined a strong pipeline of HTHP technologies from a range of suppliers. The current review confirms broader availability and stronger signals at the top end. More solutions are now credibly positioned above 160 °C, including multi-stage steam compression (turbo, rotary vane, piston, screw) and Stirling-type systems, with particular momentum in the 1 MW to 10 MW range. Reported maximum supply temperatures still reach 200 °C to 280 °C in defined use cases, often via open or semi-open steam cycles. At the same time, the 120 °C to 160 °C band has thickened with robust, modular offerings suitable for replication.
On capacity, installations at or above 10 MW are expanding, in particular where process-gas-derived centrifugal compressors (for CO_2, steam, and select HFO/HCFOs) are applied. The largest single HTHP systems in realised projects have increased in size, and district-heating style platforms are being implemented into industrial hubs. The relationship already seen in Project 58 - higher feasible supply temperatures at larger capacities- is even clearer in the updated dataset. Architecturally, cascade and hybrid designs that combine hydrocarbon cycles with steam compressors appear more frequently as catalogue options. Suppliers continue to report lifetimes clustering around 20 years, with higher figures at larger scales, which is consistent with Project 58 and now supported by a wider base of multi-MW references.

Bottom line: The technology frontier has advanced at both the high temperature and high capacity ends, with more standardizable offers below 160 °C and credible pathways above 160 °C leveraging steam compression and cascades.

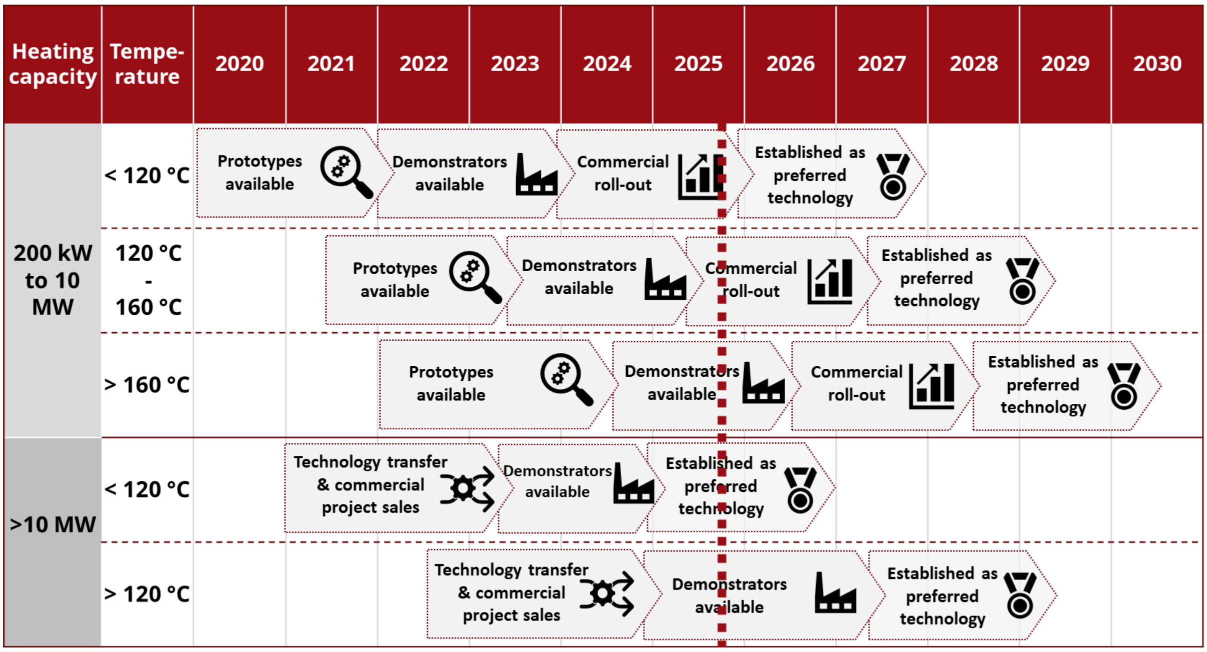

Figure 3-1: Expected roll-out of the high-temperature technology into market. Adopted from IEA HPT Project 58, Task 1 Report – B. Zühlsdorf et al. 2023[1].

3.3. Staged roll-out to 2030

The near-term market trajectory is becoming clearer.

- Below 120 °C and at capacities up to roughly 10 MW, commercial solutions adapted from industrial refrigeration are already widely available and, in many applications, preferred on total cost and risk.
- Between 120 °C and 160 °C, offerings have progressed from pilots to routine demonstrations and are now entering broader commercial availability as standard modules and cascades mature; a broad market uptake is expected during 2025–2026.
- Above 160 °C in the sub-10 MW range, deployment remains demonstration led, with early commercial adoption expected as reference plants from 2026–2028 come online.
- At or above 10 MW, commercial references are appearing from 2025 onwards, with the strongest CAPEX advantages at scale using process-gas-derived centrifugal and steam platforms.

Looking ahead, the demonstration pipeline is clearly translating into commercial roll-outs. Below 160 °C, technologies are increasingly available commercially and are being deployed at scale – multiple suppliers are delivering installations that validate performance, uptime, and O&M at hundred-kilowatt to multi-megawatt sizes. This consolidation at 100 °C to 160 °C is what Project 58 anticipated as a major facilitator for mainstream adoption of HTHPs. At the same time, the frontier is moving upward in both temperature and scale: for capacities above 10 MW, we see a new wave of large demonstration plants under construction, many targeting temperatures above 200 °C via steam compression and process-gas-derived centrifugal or ORC platforms. As these large capacity projects above 200 °C commission and circulate independently verified data, we expect rapid replication into industrial hubs and district systems, supported by learning-curve CAPEX reductions, standardized integration packages, and reliable service models. In short, the market is developing in a healthy way - with food, beverage, paper, and chemical sectors leading the way: commercial traction up to 160 °C is de-risking procurement today, while high-temperature, high-capacity demonstrations are paving the path for the next tier of decarbonization by HTHPs.

The combined acceleration in natural working fluids, higher-temperature and larger-capacity offerings, and a surge of demonstrations reinforces the self-amplifying loop - technology readiness, end-user adoption, and enabling boundary conditions. With low, stable tariffs on electricity, effective carbon pricing, and targeted support for first-of-a-kind high-temperature plants, HTHPs are positioned to contribute meaningfully to 2030 targets while establishing a mature market foundation for even higher-temperature applications thereafter.

4. References

[1] B. Zühlsdorf *et al.*, "High-Temperature Heat Pumps. Task 1 – Technologies.: Task Report," 2023.

[2] Horizon 2020, "G. Technology readiness levels (TRL)," in *Extract from Part 19 - Commission Decision C(2014)4995*, 2014.

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