HORIZON-CL5-2023-D3-02-04
Innovative components and configurations for heat pumps

ZIMBA

Zero-carbon Industrial heat production by aMmonia water aBsorption heAt transformer

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Duration: 48 months

Deliverable D1.2
Specifications of the end users' head demands and wastes - v1

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Executive Summary

Deliverable D1.2 focuses on gathering end-user requirements and identifying industrial sectors and configurations where both low-temperature steam demand and high-temperature waste heat exhaust are present, which will guide the design of the innovative AHT (Absorption Heat Transformer).

To gather end-user requirements, a structured approach has been adopted, including a literature review to identify key industrial applications for AHT, an online survey distributed to end-users through CLAUGER sales representatives, and potential follow-up interviews with available customers to clarify and refine end-user requirements.

The literature review highlighted several major industrial applications that come close to the main characteristics of the ZIMBA AHT technology, including the chemical, food, and paper industries. Potential integration concepts for AHTs have been identified in alcohol distillation plants, paper mills, and future district heating networks in densely populated areas in Europe and China, particularly in cold climates.

Previous review papers have explored the use of AHTs for waste heat recovery from industrial processes, such as cogeneration systems, distillation in chemical plants, seawater desalination, water purification, and evaporation processes.

However, so far, no process precisely matches the temperatures of the ZIMBA AHT technology. Further screening of potential processes in the food and chemical industries where 110 °C steam is needed will be a priority. Focus will be on applications where waste heat at a temperature of around 80/72 °C is available, and steam at relatively low pressure is required.

An online questionnaire has been developed and sent to 25 CLAUGER sales representatives to distribute to end-users. Responses are expected in March/April 2025 and will be incorporated into Deliverable D1.3 (due by 31 May 2025). D1.2 is directly linked to Task T1.3 (Architecture studies for the baseline & upgraded AHT systems based on end user's requirements), providing important data such as temperature levels required for AHT design.

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1. Introduction

This Deliverable D1.2 is about the identification of the process heat demands (low-temperature steam) and waste heat at high-temperature available in the targeted industrial sectors. D1.2 is elaborated in Task T1.2 about collecting end users' requirements (Lead: OST, Partners: CLAU, CEA, POL) in work package WP1 about designing the innovative AHT system (Lead: CEA).

The objective is to identify the industrial sectors and configurations where both a low-temperature steam demand and a high-temperature waste heat exhaust are present.

In focus are the food & beverage, chemical, and pulp and paper industrial sectors needing low-temperature steam.

D1.2 is linked to Task T1.3 to provide, for example, the temperatures for the AHT design.

As a next step, the Deliverable D1.3 will be established by 31 May (M6) and includes the survey results. The consistency of the data (for both heat demand and waste heat exhaust) will be analyzed in terms of global energy consumption/exhaust, potential savings to reduce the level of temperature requested, daily and yearly variations, and seasonality.

As illustrated in Figure 1, the AHT technology has 3 temperature levels and has the potential to produce 1 unit of heat at 100 to 110 °C from 2 units of low-temperature waste heat at 70 °C and only 0.02 units of electricity while releasing 1 unit of ultra-low temperature heat at 30 °C. The heating and cooling capacities required are based on the customer's requirements.

- 70 to 80 °C hot water (heat source) – 2 units
- 100 to 110 °C steam directly (heat sink) – 1 unit
- 10 to 30 °C cold water – 1 unit

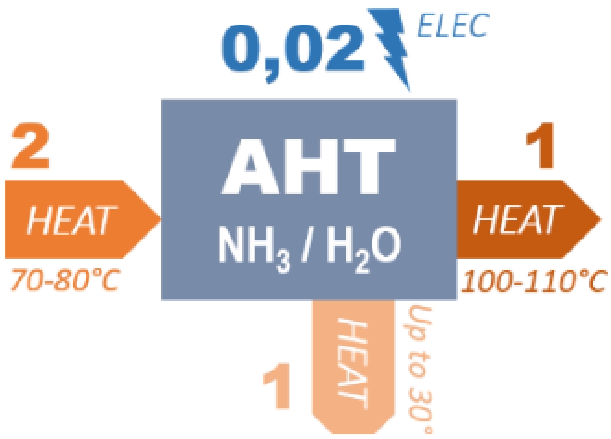


Figure 1: Illustration of the relative inlet/outlet energy fluxes requested for the operation of the ZIMBA AHT system to supply process heat at 100 °C from industrial waste heat at 70 °C with hardly any electricity consumption (CEA, 2023).

Finally, OST will explore the potential for replication and transfer of the AHT technology within other relevant industry sectors to extend the impact assessment beyond the testing facility.

2. Methodology

The methodology chosen for elaborating the end-user requirements (D1.2 and D1.3) is as follows:

- Literature Review:
    - For an initial filtering of the industrial sectors, literature research is carried out using Web of Science and Google Scholar databases.
    - The most important industrial sectors (OST), industrial applications, temperature levels, etc., are summarized.
- Questionnaire:
    - An online questionnaire is created (OST, CLAUGER review).
    - The questionnaire with the survey link is sent to end-users via the CLAUGER sales representative.
    - A standard e-mail text is created for the invitation to participate in the survey with a brief description of the objectives and goals of ZIMBA.
    - Focus is on the industry sectors: food & beverage, chemicals, and pulp & paper.
    - The target group is engineers, sales, service, and product managers.
- Interviews:
    - Based on the survey feedback, some follow-up interviews are arranged for individual available customers to clarify the end-user requirements.
- Summary/Conclusions:
    - The results of the Literature Review, Questionnaire, and Interviews are summarized in Deliverables D1.2 and D1.3.

3. Literature Review

The goal of the literature review is to identify the most relevant industries and applications where AHT technology could be applied. To this end, the databases Web of Science, Scopus and Google Scholar are searched.

Figure 2 illustrates a potential ZIMBA AHT (Absorption Heat Transformer) technology integration with a circular heat system approach into the energy system. The AHT system based on ammonia-water recovers low-temperature industrial waste heat (around 70 to 80 °C) to provide higher-temperature process heat (100 to 110 °C) necessary for vapor production or other industrial uses and releases low-temperature waste heat (below 30°C) to potential 5th generation district heating systems (CEA, 2023). A major benefit of a sorption system is that it can vaporize waste energy at a low electricity cost (Collignon et al., 2025, 2024).

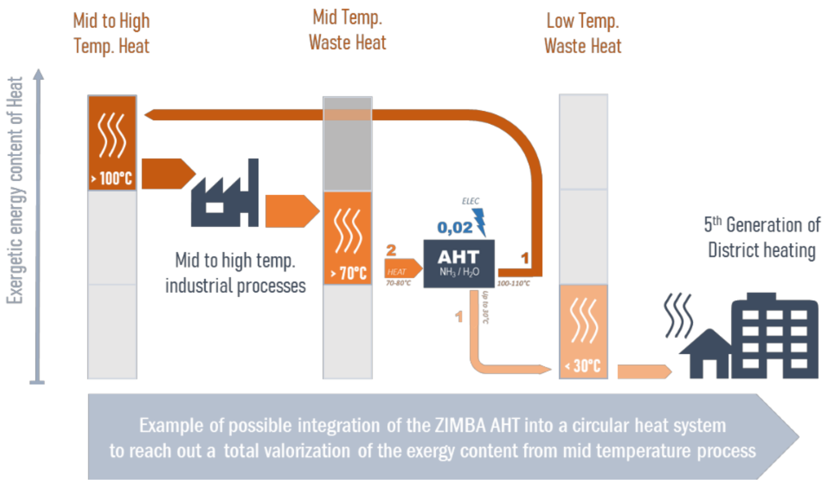


Figure 2: Illustration of potential integration of the ZIMBA AHT system into the energy system with a circularity approach (CEA, 2023).

Numerous industries need heat at high temperatures while dissipating heat at moderate to low temperatures. Figure 3 lists typical temperature ranges of processes in the food, beverage, paper, metal surface treatment, and bricks & blocks industries (CEA, 2023; Kalogirou, 2003).

Industrial Sector	Unit operation	Temperature range (°C)
Food	Drying	30-90
	Washing	60-90
	Pasteurising	60-80
	Boiling	95-105
	Sterilising	110-120
	Heat Treatment	40-60
Beverages	Washing	60-80
	Sterilising	60-90
	Pasteurising	60-70
Paper Industry	Cooking and Drying	60-80
	Boiler feed water	60-90
	Bleaching	130-150
Metal Surface Treatment	Treatment, electro-plating, etc.	30-80
Bricks and Blocks	Curing	60-140

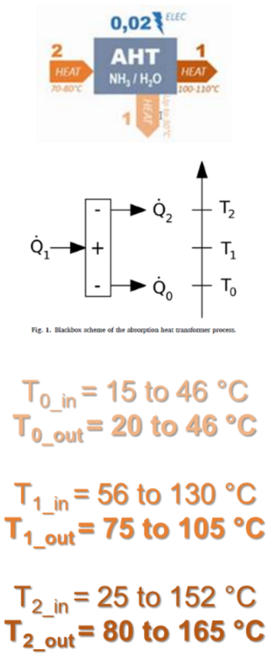
Figure 3: Typical temperature ranges of the process heat demands in the food, beverage, paper, metal surface treatment, and bricks & blocks industries (Kalogirou, 2003).

Cudok et al. (2021) reviewed 43 AHT installations in the order of 1 MW heating capacity with a total capacity of around 134 MW (see the table in Figure 4). Today, most AHT installations operate in East Asian countries: 12 are in China, 2 in Japan, 1 in Germany, 1 in Italy, and 1 in the USA. Most of the reported AHT machines use the $H_2O/LiBr$ working fluid (40 out of 43 installations), which enables better performance than other working pairs in terms of heat exchange.

The temperatures of the installations are in the following ranges:

- T_{2_in} / T_{2_out} = 25 to 152 °C / 80 to 165 °C
- T_{1_in} / T_{1_out} = 56 to 130 °C / 75 to 105 °C
- T_{0_in} / T_{0_out} = 15 to 46 °C / 20 to 46 °C

37 AHT installations among the 43 listed operate with a driving heat $T_{1,in}$ of 75 to 110 °C, which is in the range of the NH_3/H_2O AHT to be developed in ZIMBA. According to Cudok et al. (2021), the major manufacturers are Ebara (12), Hitachi Zosen (8), Tokyo Sanyo Electric (6), Thermax (4), and Hitachi (3). Today, Shuangliang (China) and World Energy (Korea) are currently on the market. Hitachi and Tokyo Sanyo don't offer AHT anymore.



Technical information of installations, Working pair: $H_2O/LiBr$, except No. 21, 4 (NaHO) and 19 (N/A), * marks assumptions based on given information, E: Evaporator, G: Generator.

No.	Capacity [MW]	$T_{0,in}$ [°C]	$T_{0,out}$ [°C]	$T_{1,in}$ [°C]	$T_{1,out}$ [°C]	$T_{2,in}$ [°C]	$T_{2,out}$ [°C]	cycle	COP	references
43	1.83	32	N/A	100	N/A	N/A	148	Double	N/A	authors
42	0.55	20	N/A	130	N/A	N/A	148	Single	N/A	authors
41	0.64	32	N/A	100	N/A	N/A	130	Single	N/A	authors
40	0.89	23	29	96.1	80	139	144.5	Single	0.47	authors
39	4.68	32	N/A	56	N/A	N/A	80	Double	N/A	authors
38	0.77	32	N/A	56	N/A	N/A	90	Double	N/A	authors
37	1.04	32	N/A	115	N/A	N/A	120	Single	N/A	authors
36	0.67	32	N/A	91	N/A	N/A	165	Double	N/A	authors
35	1.8	32	N/A	97	N/A	N/A	130	Single	N/A	authors
34	42.17	32	N/A	120	N/A	N/A	158	Single	N/A	authors
33	1.2	N/A	N/A	93	75	125	135	Single	0.46	[8] authors
32	2.61	28	N/A	105	100	N/A	144	Single	N/A	authors
31	4.19	28	38.5	108	100	152	157	Single	0.47	[8] authors
30	0.45	N/A	N/A	90	80	95	105	Single	0.47	[8] authors
29	1.83	30	N/A	97	N/A	N/A	125	Single	N/A	authors
28	1.65	15	N/A	81	81	120	125	Single	0.46	[37] authors
27	2.48	25	30	78	78	107	112	Single	0.45	[38] authors
26	0.15	27	32	90	85	133	137	Single	0.48	[38,39] authors
25	5	28	30	98	N/A	N/A	110	Single *	0.47	[40,41]
24	7	28	30	98	N/A	N/A	110	Single *	0.47	[8,41]
23	7	28	30	98	N/A	N/A	110	Single *	0.47	[8,41]
22	4	N/A	N/A	80	N/A	N/A	140	Double	N/A	[42]
21	0.08	46	46	98(G) 105(E)	98(G) 105(E)	115	120	Single	N/A	[32]
20	4.1	20	26	90	85	110	130	Single	0.46	[14]
19	2	N/A	N/A	97	94.5	N/A	133	N/A	N/A	[20]
18	3.37	26.7	30.6	78.7	78.7	N/A	111.5	Single	0.48	[43]
17	1.2	N/A	N/A	78	N/A	N/A	108	N/A	N/A	[44,45]
16	N/A	22.3	N/A	88	N/A	N/A	122	N/A	N/A	[44,45]
15	1.38	22	31.4	100	100	100	136	Single	0.44	[20,46]
14	1.1	N/A	N/A	100	100	N/A	144	Single *	0.44	[20,47]
13	1.09	27	30	125	91	134	139	Single *	0.49	[20,48]
12	2.71	32	37	95	95	25	131	Single *	0.47	[20,48]
11	1.88	31	37	100	100	90	143	Single	0.48	[44,45]
10	0.35	32	37	95	85	95	120	Single *	0.49	[20,48]
9	6.78	10.7	36.6	103.3	103.3	130.8	144.9	Single	0.49	[20,47–49]
8	3.3	31	37	100	100	90	143	Single *	0.48	[20,48]
7	1.67	15	20	80	80	111	116	Single *	0.48	[20,48]
6	0.93	20	30	80	80	119	124	Single *	0.48	[20,48,50]
5	1	N/A	N/A	100	100	N/A	145	N/A	N/A	[20]
4	2.35	31	N/A	98	88	127	132	Single *	0.48	[20,48]
3	1.88	32	36	80.5	80.5	100	112	Single *	0.48	[20,48]
2	1.66	28	32	83	83	100	111	Single	0.48	[9,20,48,51]
1	2.35	26	32	98	88	127	133	Single	0.47	[20,48,50]

Figure 4: Temperature ranges of 43 absorption heat transformer installations (Cudok et al., 2021).

The applications of AHTs in the industrial sector are approximately (Cudok et al., 2021):

- 61% chemical industry (26 out of 43),
- 9% food industry (4),
- 16% different sectors (7), e.g., heavy industry and paper industry
- 14% of others with no information (7).

Typically, the heat flow at the low-temperature level T0 is rejected to the ambient (via cooling towers, seawater, or groundwater). The driving heat is typically waste heat (Cudok et al., 2021).

(Braccio et al., 2021) presented a study on an ammonia-water AHT for a combined cooling and power (CCP) production system from a low-temperature heat source. Former reviews from Parham et al. (2014) and Donnellan et al. (2015) on AHT evaluated 99 and 106 references of AHTs and their applications. Rivera et al. (2015) reviewed the state of the art of AHT with a focus on waste heat recovery from industrial processes, including:

- cogeneration systems,
- distillation in chemical plants,
- desalination or water purification (i.e., seawater desalination and distillation),
- evaporation processes, and
- other applications.

Several AHT prototypes have been developed with capacities that vary from 700 to 5’000 W and with COPs between 0.15 and 0.43 and purified water capacities that varied between 0.6 and 1.6 kg/h per kW of power supplied to the heat transformer (Rivera et al., 2015).

Garone (2018) and Garone et al. (2017) built an ammonia-water AHT prototype with reliable and stable operation with waste heat temperatures ranging from 60 to 64 °C and a cold sink at 8 to 16 °C (suitable for dry-cooling in winter), gross temperature lifts (GTL) up to 25 K were obtained, and thermal COP in the range 0.35 to 0.47.

Besides industrial applications, the integration of an AHT in district heating systems should be considered. Highly populated locations in Europe and China with cold climates are gaining importance for consistent and concentrated district heating applications (Garone, 2018). The current trend is going towards lower supply temperatures. Nevertheless, the average supply temperatures are around 86 °C in Sweden and between 70 and 120 °C in Denmark (Garone, 2018; Garone et al., 2017).

Toppi et al. (2021) highlighted a compressor-assisted heat transformer for waste-heat-powered district heating applications. Using waste heat at 50 and 60 °C and heat rejection temperature at 0 °C and -10 °C, it is possible to upgrade heat up to 120 °C with an electrical COP above 4, a thermal COP of about 0.5, and an upper pressure below 40 bar.

Already in 1997, Groll (1997) reviewed the state of research on absorption/compression cycle technology. It was found that the COP improves more when the temperature glides of the heat sink and source fluids are larger, with vertical shell-and-tube heat exchanger designs performing best. Research needs were identified, such as absorber and desorber design, compressor lubrication, and sensitivity to changes in operating parameters, such as variations in heat source or sink temperatures.

Based on this literature screening, the following cases were selected that come close to the objective of the ZIMBA project (see temperatures in Figure 1), namely applications for distillation and paper manufacturing. Figure 5, Figure 6, Figure 7, and Figure 8 illustrate possible integration concepts of AHT in:

- an alcohol distillation plant (Cudok et al., 2021),
- an industrial plant (capacity: 150 kW) (Cudok et al., 2021),
- a virtual paper mill (CEPI), and
- a future 4th generation district heating network *c*

The temperature ranges (T2, T1, and T0) are:

- 107/112 °C, 78 °C, 25/30.5 °C
- 133/137 °C, 85/90 °C, 27/32 °C
- 10 bar(g) steam (184 °C), 60/80 °C, 15/45 °C
- 80/70 °C, 35/55 °C, 10/15 °C

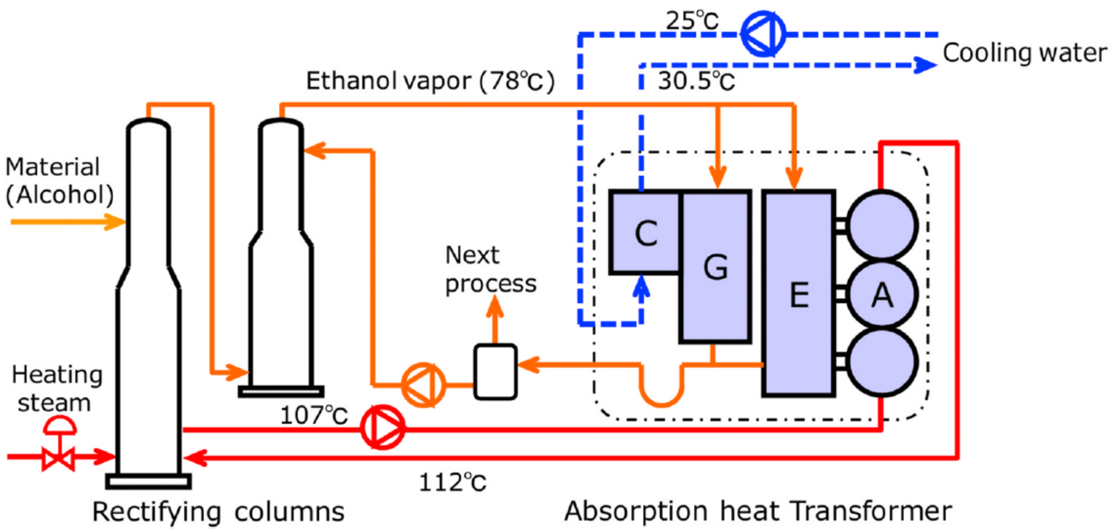


Figure 5: AHT installed in an alcohol distillation plant (Cudok et al., 2021).

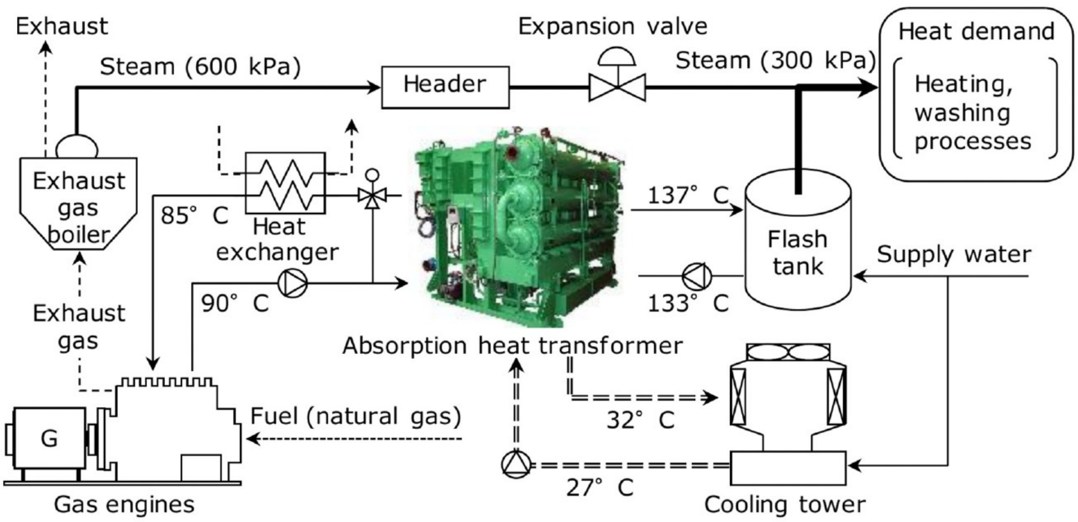


Figure 6: AHT installed in an industrial plant (capacity: 150 kW) (Cudok et al., 2021).

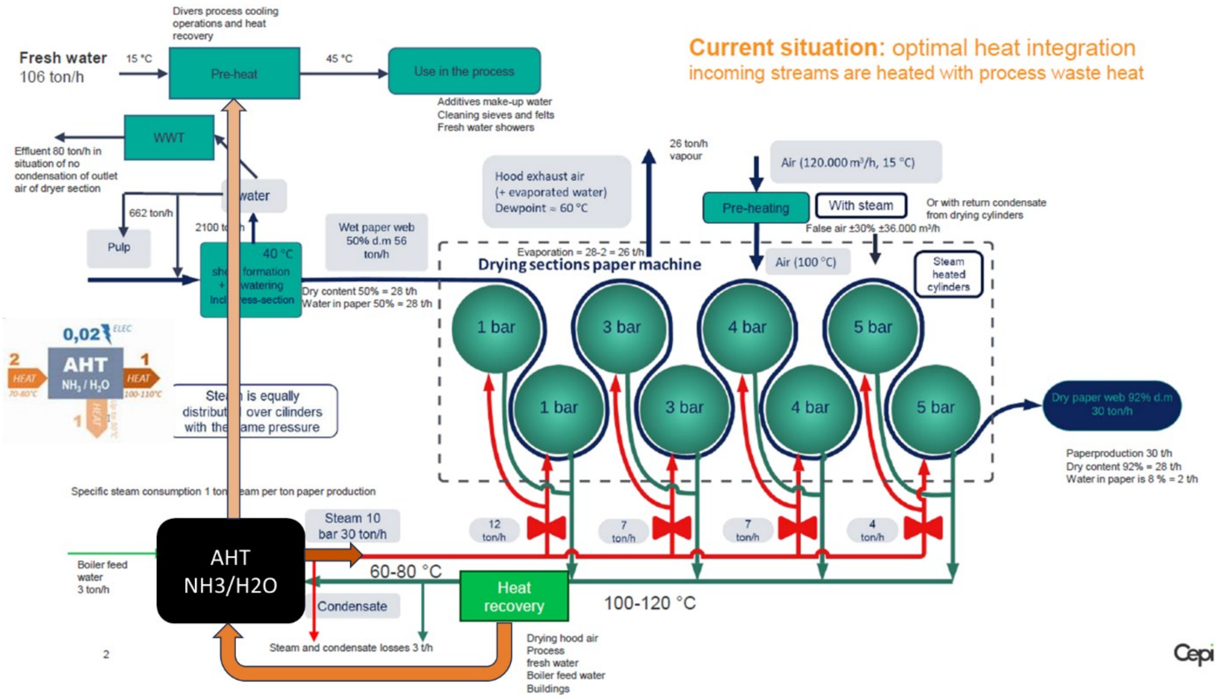


Figure 7: A possible AHT integration in a virtual paper mill (Source: CEPI).

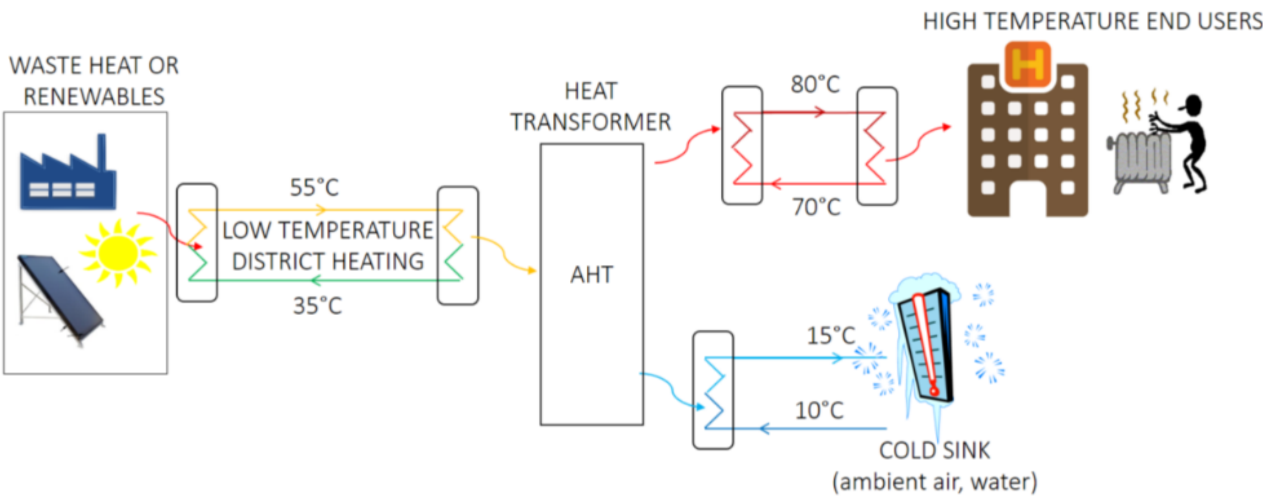


Figure 8: Integration of an AHT in future 4th-generation district heating networks (Garone, 2018).

The application of the alcohol distillation plant seems to be feasible for the ZIMBA AHT technology, but it has the characteristics of an isothermal heat source, which may not be very representative. Challenging are the heat flows to and from the AHT. In the evaporator (E) and generator (G) there is condensing ethanol vapor, meaning no temperature glide, which is detrimental concerning COP. In the condenser (C) the temperature of the cooling water seems to be fixed (maybe due to a cooling tower). As a result, the benefits of using an ejector under cut-off conditions no longer apply. In the absorber (A), there is a temperature glide from 107 to 112 °C, suggesting a subcooled liquid. In comparison, the AHT in the ZIMBA projects aims to generate steam in the absorber.

The case study of the industrial plant may be considered too stretched for the ZIMBA AHT technology. However, it would be possible to lower the steam temperature or the heat dissipation temperature to see what the AHT technology can do.

The AHT integration in the virtual paper mill might be even more challenging, producing steam just above the atmospheric pressure and then adding an MVR system to increase the steam pressure to the required 10 bar(g). The 45 °C of the return cooling water could also be a challenge for the ZIMBA AHT technology.

The application of a future 4th generation district heating network has the issue of not producing steam, which is a key element in the ZIMBA project.

Overall, the following conclusions can be drawn from the literature reviews:

- This literature review offers an overview of different processes with temperature ranges that come close to the main characteristics of the ZIMBA AHT system. So far, no process precisely matches the temperatures of the ZIMBA AHT technology. However, the concept of AHT could be interesting for a wide range of industries, especially food/chemical/district heating, with different temperature requirements.
- Further screening of potential processes in the food and chemical industries where 110 °C steam is needed will be a priority. The focus will be on applications where waste heat at a temperature of around 80/72 °C is available, and steam at relatively low pressure is required. In fact, the temperature of the driving heat is the main limitation, while the steam can be raised further with an MVR (mechanical vapor recompression) system if a higher steam pressure is required.
- The feedback from the questionnaire should provide more details on suitable integration cases (D1.3). The possibilities of AHT integration will be further addressed in WP4. The aim is to search the food and chemical industry for processes that require 110 °C steam.

4. Questionnaire

An Online Questionnaire (Figure 9) for industrial companies has been established and sent to CLAUGER customers via their sales representatives. Answers are expected in March/April 2025 to be integrated into the Deliverable D1.3 (due by 31 May 2025).

The objective is to gather direct feedback from CLAUGER's customers to determine in which industries and processes the ZIMBA AHT technology best fits the end-user requirements. The questionnaire includes questions on industries, processes, typical heat requirements, heat flows, capacities, temperature conditions, etc. Possibly, follow-up interviews can be organized with interested customers from the food & beverage, chemical, and pulp & paper industries to clarify the requirements of the end-users further.

Figure 9: Online Questionnaire for industrial companies.

The questionnaire consists of 32 questions (some open, some with multiple answers possible):

No.	Questions
1	What is your company name? • …
2	In what industrial sectors are you active? (multiple answers possible) • Food & beverage • Chemicals • Pharmaceutical • Pulp & paper • Textiles • Metal • Minerals • Others
3	If [Others], please write some comments: • …

4	What products do you produce? (open question, write some key words) • …
5	In which geographical markets are you active? (multiple answers possible) • Africa • North America • Latin America • Asia • Europe • Others
6	If [Others], please write some comments: • …
7	What industrial processes do you have in your factory? (multiple answers possible) • Drying • Evaporation • Distillation • Cooking • Others
8	If [Others], please write some comments: • …
9	Do you have heating and cooling needs in your factory? • Yes • No
10	Which media do you use for heating and cooling? (multiple answers possible) • Water • Air • Steam • Others
11	If [Others], please write some comments: • …
12	What pressure and temperature levels do you have in your factory? (multiple answers possible) • High-pressure steam 6 to 12 bar(a) • Low-pressure steam 1 to 6 bar(a) • Pressurized hot water (80 to 100°C) • Hot water (60 to 80°C) • Warm water (30 to 60°C) • Cold water (10 to 30°C) • Chilled water (0 to 10°C) • Hot air • Others
13	If [Others], please write some comments: • …
14	What is your main energy carrier? (multiple answers possible) • Gas

	• Oil • Electricity • Biomass • Others
15	If [Others], please write some comments: • …
16	What heating technologies do you have in operation? (multiple answers possible) • Steam boiler (fossil fueled) • Biomass boiler • Electrode boiler • Air heater (fossil fueled) • Heat pump • Others
17	If [Others], please write some comments: • …
18	What cooling technologies do you have in operation? (multiple answers possible) • Chiller • Freezer • Cooling tower • Others
19	If [Others], please write some comments: • …
20	Do you have waste heat in excess available at 70 to 80 °C that must be rejected? (multiple answers possible) • Yes • No • No, but at another temperature level: …
21	If [No, but at another temperature level], please write some comments: • …
22	If yes, at what capacity? (multiple answers possible) • <100 kW • 100 to 500 kW • 500 kW to 1 MW • 1 to 5 MW • >5 MW
23	What cooling technology is used to reject the waste heat? • Dry cooler (ambient air) • Cooling tower • Others
24	If [Others], please write some comments: • …
25	Do you need a significant amount of low-temperature heat between 10 to 30 °C? • Yes

	• No
26	If yes, at what capacity? (multiple answers possible) • <100 kW • 100 to 500 kW • 500 kW to 1 MW • 1 to 5 MW • >5 MW
27	If yes, what kind of heating technology is used? • …
28	Do you have a process around 100 to 110°C that needs a significant amount of energy? • Yes • No
29	If yes, at what capacity? (multiple answers possible) • <100 kW • 100 to 500 kW • 500 kW to 1 MW • 1 to 5 MW • >5 MW
30	If yes, what kind of process? (open question, write some key words) • …
31	If yes, is the process running continuous? • Yes • No
32	Are you okay with being contacted again to discuss this in further detail? • Yes • No

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6. Degree of progress

The degree of fulfillment of the task activities in relation to what is outlined in the DoA is about 50%.

7. Dissemination level

The dissemination level of this Deliverable D1.2 is public.