Push2Heat

D3.3

DEMONSTRATION SITE AT CDG - DEMO 3 - SYSTEM DESIGN

V0.1

Grant agreement No: 101069689

From: TECNALIA

Prepared by: Laura Alonso, Jose Luis Corrales

Date: 24/10/24

Funded by the European Union

Push2Heat

DELIVERABLE

Basic information on the deliverable	
Dissemination level	Public
Type	Report
Due date	30/09/24
Task	Task 3.1.3
Task leader	Tecnalia
Authors	Laura Alonso, Jose Luis Corrales

VERSIONS

No.	Name	Partner	Contribution	Date
V01	Laura Alonso, Jose Luis Corrales	TECNALIA	First version of the report	24/10/24

Funded by the European Union

Push2Heat

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Funded by the European Union

ABBREVIATIONS

PUSH2HEAT	Pushing forward the market potential and business models of waste heat valorisation by full-scale demonstration of next-gen heat upgrade technologies in various industrial contexts.
AHT	Absorption Heat Transformer
CHP	Combined Heat & Poweer
COP	Coefficient of Performance
DH	District Heating
EES	Engineering Equation Solver
FT	Flash Tank
HTHP	High Temperature Heat Pump
HUT	Heat Upgrading Technology
KPI	Key Performance Indicator
P&ID	Piping & Instrumentation Diagram
PER	Peformance Efficiency Ratio
PM	Paper Machine
SGM	Steam Generation Module
SPF	Seasonal Performance Factor
TC	Thermocompressor
ΔT thrust	Temperature Thrust
ΔTlift	Temperature Lift
ΔΔT	Characteristic driving temperature difference

Funded by the European Union

1. INTRODUCTION

1.1. Overview of demonstrators in Push2heat project

PUSH2HEAT is an EU-funded project aimed at scaling up heat upgrading technologies (HUT) to overcome technical, economic, and regulatory barriers. The project focusses on four different technologies with supply temperatures ranging from 90°C to 160°C, integrating them into the paper and chemical industries. Demonstrations of the four technologies will take place at selected industrial sites. The project also aims to develop business models and exploitation roadmaps for increased market penetration of heat upgrading technologies. The overall project duration of PUSH2HEAT is 48 months.

The recovery and upgrade of waste heat with high-temperature heat pumps in industrial processes plays a significant role for decarbonizing the industry and providing sustainable and environmental alternatives to the conventional energy supply systems based on fossil fuels. A wide deployment of such systems can be accelerated by generating experience through successful integration, highlighting the industrial related technical challenges and demonstrating energy efficiency gains generated throughout the operation.

In PUSH2HEAT the heat upgrade systems based on electrically and thermally driven heat pumps are located at three demonstration sites in Germany (Demo 1) and Italy (Demo 2 and Demo 3). A fourth heat upgrade system is based as an industrial scale system and test site in Belgium aiming at demonstrating the application potential of the thermochemical heat pump technology (see Figure 1). For each demonstration site the main coordinator is given by the following research partners:

- Demo site 1 (Germany): Fraunhofer Gesellschaft zur Förderung der Angewandten Forschung E.V.
- Demo site 2 (Italy): Politecnico di Milano
- Demo site 3 (Italy): Fundación Tecnalia Research & Innovation

Funded by the European Union

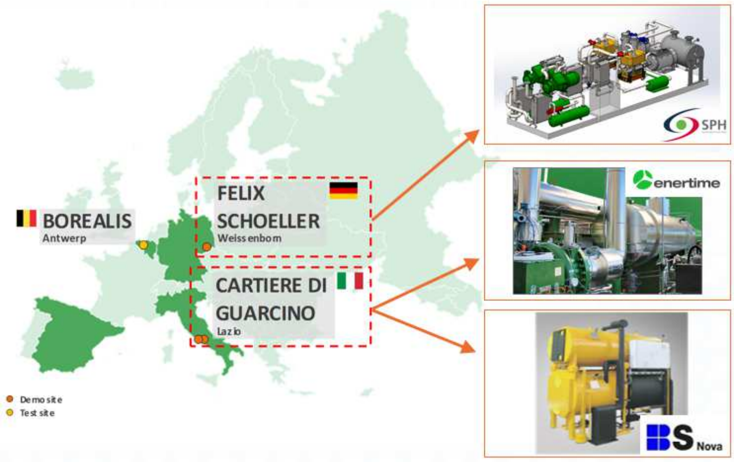

Figure 1: Heat upgrade systems in PUSH2HEAT

Demo 1 will integrate a High Temperature Heat Pump (HTHP) in Felix Schoeller GmbH & Co. KG paper mill in Weissenborn, Germany. Demo 2 and Demo 3 will be installed in the same location, in Cartiere di Guarcino's paper mill in Lazio, Italy. Demo 2 will integrate a High Temperature Heat Pump (HTHP) and Demo 3 will integrate an Absorption Heat Transformer (AHT).

1.2 Contents of the report

This report (deliverable D3.3) describes the results gained from analyzing the requirements of Demo site 3 in Italy (Guarcino, Lazio), planning the optimal integration of the heat upgrade technology into the industrial process (paper production) a basic engineering for the installation. First engineering results undertaken among the partners involved will be presented and discussed.

Section 2 describes the analysis and requirements of the Demo site of AHT in CDG. Firstly, the current energy consumption of fossil-fuelled systems is described. The description of energy produced and consumed in the plant and the different pressure levels of steam is provided. The waste heat source available in plant is described, as well as the most suitable upgraded heat sink and rejection circuit for the AHT.

Section 3 describes the selected case's preliminary planning and basic engineering for HUT (AHT) integration. It describes the system configuration, with the corresponding functional P&ID including all auxiliary components, with the specifications for AHT control and steam generation module control. Moreover, an overview of the monitoring concept is presented.

Funded by the European Union

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

2. Analysis and requirements

2.1. Demo site

Cartiere di Guarcino is an industrial group located in Guarcino in Lazio (Italy). The company heritage lies in the production of decor paper for high- and low-pressure lamination and flooring paper. Their products include Unicolor, Backer papers, Print base paper and Underlay. The plant occupies an area of 144 000 square meters, and it has a production capacity of 50 000 t of paper per year, thanks to the commitment of 170 employees.

Paper production is an energy intensive process, requiring considerable amounts of steam. Since the foundation of the plant in 2003 the steam was entirely produced by gas boilers on site. However, in 2006 the team behind CDG invested in a dedicated energy company named Bio Energia Guarcino (BEG), a specialized facility equipped with a technologically advanced cogeneration plant that uses animal fats and vegetable oil residues as fuel. Such a plant produces both electrical and thermal energy, allowing CDG to decrease the production of the on-site gas boilers.

The company is also committed to avoiding any unnecessary use of water from the river flowing nearby the plant and to maximize the production efficiency, to reduce the production cost as well as any paper waste.

Figure 2 shows an aerial view of CDG. The plant could be divided into three main areas: production site, generation site and offices/other buildings (canteen, etc.).

The production site consists of two paper machines, enclosed in two warehouses located in the upper part of Figure 2. The generation site includes two gas boilers and the CHP plant (combined heat and power), as shown in Figure 2. The steam produced by the engines and the boilers is collected at the "steam distribution site" (see Figure 2), tuned to the appropriate pressure level and distributed in the plant.

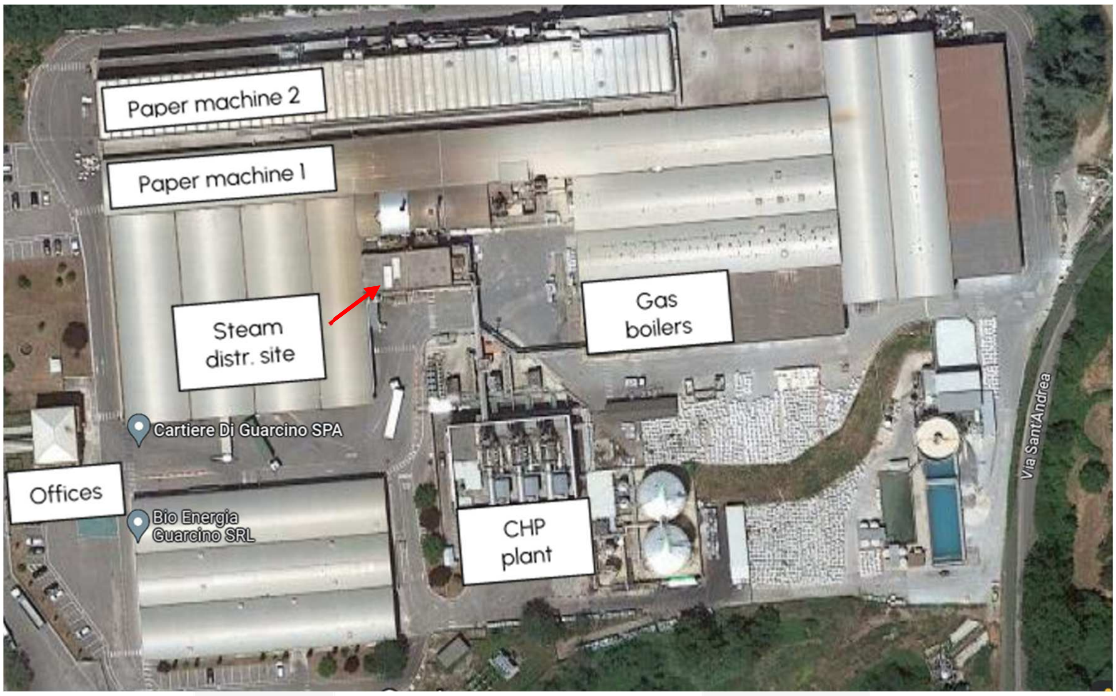

Figure 2: CDG and BEG aerial view

2.2. Current energy production systems in CDG and energy demands

The energy requirements of CDG are partially satisfied by the cogeneration plant of BEG, which generates energy in three forms: steam, hot water and electricity. CDG is also facilitated with two fire tube boilers that cover the remaining steam demand of the plant. The boilers require a yearly supply of 7 544 633 m^3 of natural gas. Eventually, CDG is connected to the national grid for the supply/sale of electricity.

The two gas boilers are manufactured by Bono Energia and they generate steam at a pressure of 14.5 bar(a), corresponding to a temperature of saturated steam of 197 °C. The duty of the two boilers is almost constant throughout the year, with a capacity of 15 to 16 t/h of generated steam, which corresponds to most of the steam used in the paper production processes of CDG, is collected in the high-pressure collector: around 2 t/h is used in some thermocompressors that are exploited to upgrade low-pressure steam from different processes to an intermediate useful pressure level for other processes. The remaining amount of 13 to 14 t/h is expanded in a valve to 6.5 bar(a) and united with the steam coming from the CHP plant.

The CHP plant owned by BEG is constituted of three biomass engines, each of which is devoted to the production of electrical energy, steam and hot water used for district heating (DH). The rated nominal electrical capacity of each engine is 6.8 MW. The generated electricity is partially used inside of CDG facilities, while the excess production is exported to the national electricity grid.

CDG has a yearly demand for electricity and heat equal to 42.12 GWhel and 101 GWhth respectively. The heat demand is in the form of steam and hot water. The hot water is mainly destined for space heating while a small portion is used for other domestic needs.

Figure 3 below illustrates the daily tons of hot water transferred from the cogeneration plant of BEG to CDG for the period between 01/01/2022 and 25/06/2023.

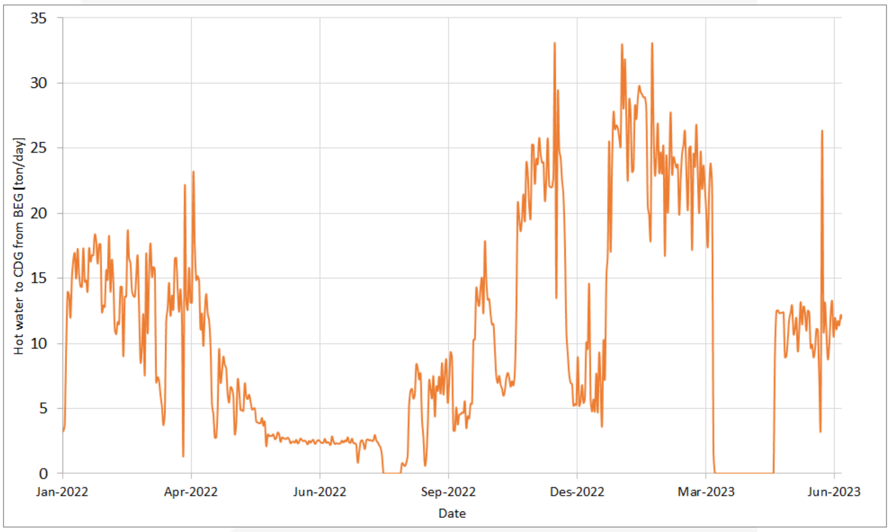

Figure 3. Hot water transferred from BEG to CDG for the period 01/01/2022 - 25/06/2023

As for CDG's electricity consumption, the plant typically consumes approximately 140 MWh per day, with nearly 100 % of this power being supplied by BEG, except for days when all the three engines of BEG are simultaneously out of operation. Figure 4 illustrates the daily electrical energy exported from BEG to CDG.

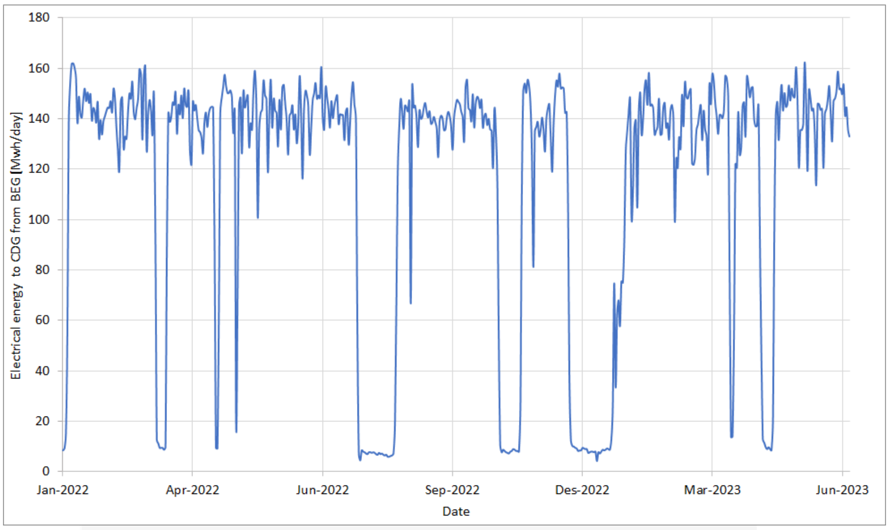

Figure 4. Electrical energy sold to CDG by BEG

The energy consumption of CDG production site is in the form of saturated steam. The two paper machines (PM1 and PM2) of CDG consume 10 t/h and 13 t/h of saturated 6.5 bar(a) steam, respectively. Of the overall 23 t/h, about 7-8 t/h is supplied by BEG, while the rest is covered by the two fire boilers that produce saturated steam at 14.5 bar(a). Figure 5 shows the daily amount of steam transferred to CDG from BEG for the period of 01/01/2022 to 30/06/2023.

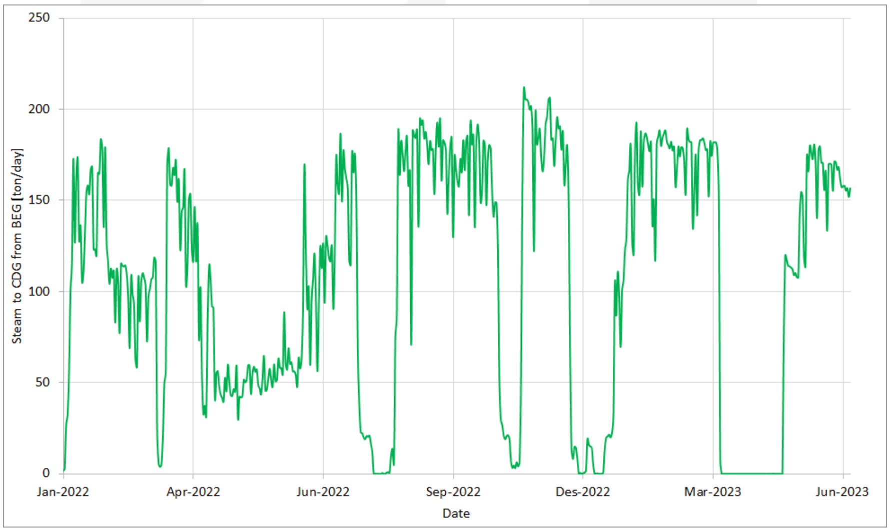

Figure 5. Steam transferred from BEG to CDG

2.3. Analysis of potential heat source

The potential heat source for Demo 3 has been identified in the cooling water of the cogeneration plant of BEG, and is coincident with the heat source of Demo 2. Therefore, the available waste heat will be distributed to both HUTs, the HTHP (Demo 2) and the AHT (Demo 3).

After cooling the cogeneration motors, the hot water stream needs to be cooled down to its supply temperature set point. The district heating network partially exploits the heat derived from the process of cooling this water stream, while currently the remaining part of it is discarded to the ambient through dry coolers. This heat rejected in the dry coolers is identified as the waste heat source for the PUSH2HEAT project and the Heat Upgrade System.

Figure 6 provides a clearer depiction of the cooling water circuit's schematic and its integration with the overall process. A more detailed explanation of the available waste heat source in the plant, from which the boundary conditions of Demo 2 (HTHP in CdG) were defined, is available in D2.2 Demonstration site at CdG – System design. Considering the amount of waste heat already calculated for Demo 2, the waste heat available for Demo 3 will be around 700 kW. This will be the nominal condition for the waste heat source.

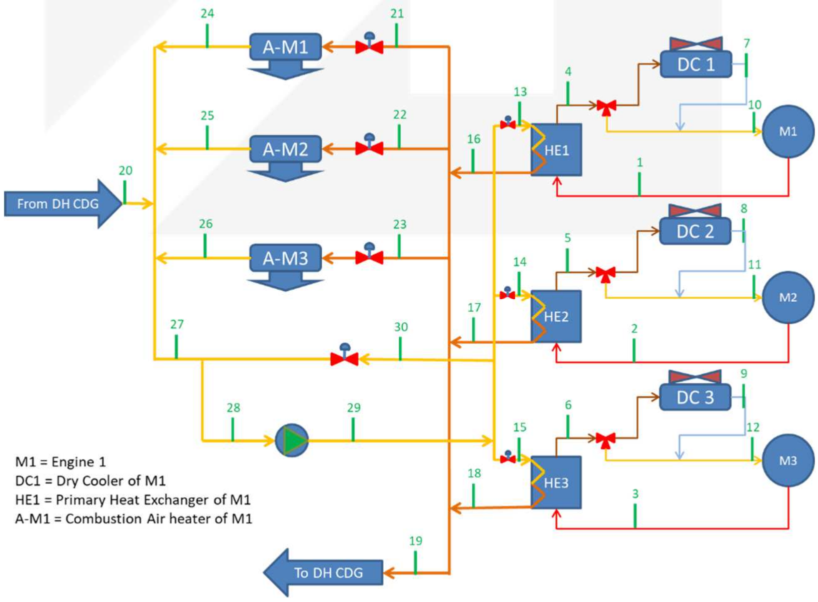

Figure 6: Schematic of water's cooling water circuit and its integration with the overall system

Funded by the European Union

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

2.4. Heat sink requirements

The steam produced by the boilers in CdG is collected in the high-pressure collector: around 2 t/h is used in some thermocompressors that are exploited to upgrade low-pressure steam from different processes to an intermediate useful pressure level for other processes. The remaining amount of 13 to 14 t/h is expanded in a valve to 6.5 bar(a) and united with the steam coming from the CHP plant. Based on the steam consumption conditions in CdG, it has concluded that the most suitable heat sink for the HUT is steam at 6.5 bar(a), needed for the two paper machines. As indicated in Section **¡Error! No se encuentra el origen de la referencia.**, around 23 t/h of steam at 6.5 bar(a) are used inside the two paper machines (PM1 and PM2), divided in 13 t/h consumed by PM2, while around 10 t/h by PM1.

Therefore, the high-pressure sink of the HUT will be the main steam collector of the plant, which works at a pressure of 6.5 bar(a). This collector is currently supplied by steam produced by the boilers and by the HRSG of the CHP plant.

The machines PM1 and PM2 work almost at full load throughout the year, apart from two maintenance weeks, one in August and one in December each year. This results in a theoretical operation time of 8 424 h/a. Further, the machines may have to stop due to problems in one of the subsections or for a change in production that can further reduce the operation time. However, even in those cases, the steam consumption of one machine stabilizes at about 30 % of the nominal consumption to maintain the temperature in the production parts. It is rare that both paper machines go out of operation at the same time.

In the scenario where PM2, i.e. the machine with the higher steam demand, is out of operation, the steam required by the plant is still about 14 t/h.

A more detailed explanation of the required heat sink in the plant, from which the boundary conditions of Demo 2 (HTHP in CdG) were defined, is available in D2.2 Demonstration site at CdG – System design.

Funded by the European Union

2.5. Heat rejection circuit

The AHT needs for its operation a third fluid stream at lower temperature for heat rejection. The source available in CdG for this purpose is water from the river, which is presently already used in the plant. Therefore, a low temperature water distribution from the river is available.

In practice, the heat rejection circuit of the AHT will be in fact useful heat for the plant, taking into account that the water taken from the river is heated up with steam in the present, in order to be used in certain processes. Therefore, the total useful heat provided by the AHT will be the sum of the upgraded heat in the absorber, and the cooling heat of the condenser. This leads to a higher COP.

3. Preliminary planning and basic engineering

3.1. Process integration of the Heat Upgrade System

Taking into account the waste heat source, upgraded heat, and rejection circuit conditions, the best HUT configuration has been developed iteratively.

An absorption heat transformer (or type 2 absorption heat pump) is a thermally driven heat pump (Keith et. al). Its internal processes include the absorption and desorption of refrigerant in a sorbent. There are different working pairs of sorbent-refrigerant, but the technology developed in Push2heat works with water-lithium bromide salt (LiBr), the refrigerant.

The heat transformer, from the point of view of external heat sources and sinks, which are used to activate and obtain the machine's useful effect and dissipate heat, works at three temperature levels. Figure 7 shows the temperature levels and thermal fluxes in the cycle. The three temperature levels at which an AHT works and the main components involved include:

- The driving heat introduced in the evaporator and generator at a temperature level T1.
- The useful effect, the heat upgrade, occurs in the absorber due to the exothermic nature of the water absorption by the saline solution. The driving heat is upgraded to a temperature level T2.
- Finally, the condenser dissipates part of the driving heat at a temperature level T0.

Funded by the European Union

A detailed explanation of AHT characteristics can be found in D2.6 of Push2heat project: Techno-economic map of Heat Upgrade Technologies.

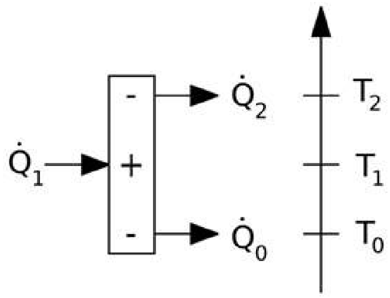

Figure 7. Heat flows in an AHT: Recovery (Q1), revaluation (Q2) and dissipation (Q3) at their corresponding temperature levels.

Figure 8 shows the configuration of Demo 3. The Absorption Heat Transformer (AHT) has three circuits, the heat rejection circuit at low temperature, the waste heat or driving heat circuit at medium temperature, and the upgraded heat circuit at high temperature.

The upgraded heat circuit provides hot water and is connected to the Steam Generation Module (SGM), comprised by a flash tank (FT), where low-pressure steam is produced, and a turbocompressor (TC), where medium-pressure steam is produced by mixing the low-pressure steam from the FT with high-pressure steam at 14.5 bar(a) from the plant.

Waste heat from the cooling circuit of the cogeneration plant is available at 90 ºC, and cooling water from the river at 15 ºC. The requirement for high temperature heat sink (upgraded heat) is steam at 6.5 bar(a) (169 ºC).

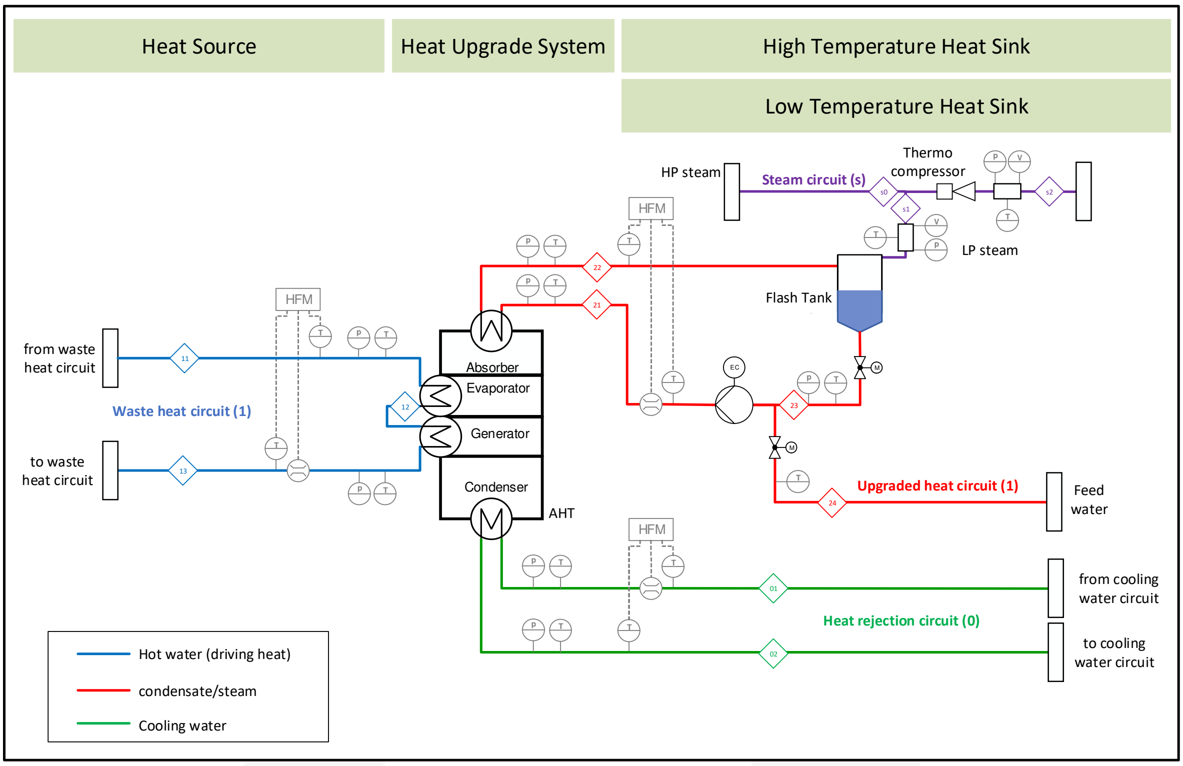

Figure 8. Simplified PID of Demo 3

Different working conditions have been tested in a thermodynamic model of the AHT + FT in order to set the working conditions of the system. Figure 9 shows the graphical scheme of the thermodynamic model developed in Engineering Equation Solver (EES). The model combines the AHT operation with the steam generation in the flash tank based on the pressure difference between the inlet and the outlet.

The characteristic equation model of an AHT presented by Corrales et al. has been used for the calculation of the upgraded heat capacity (heat produced in the absorber of the AHT). The characteristic driving temperature difference ($\Delta\Delta T$) is an indicator of the heat transfer potential of an AHT. It depends both on the temperature lift ΔT_{lift} (which is the difference between the high temperature T2 and the medium temperature T1 levels of the AHT), and the temperature thrust ΔT_{thrust} (which is the difference between the medium temperature T1 and the low temperature T0 levels). The $\Delta\Delta T$ definition is included in equation (1), in which R is a constant around 1.15.

$$\Delta\Delta T = R \cdot \Delta T_{thrust} - \Delta T_{lift} = R \cdot (t_1 - t_0) - (t_2 - t_1) \qquad (1)$$

Funded by the European Union

In the AHT, hot water generation at 141.5 ºC in the absorber has been set as the nominal conditions, and a generation of 3.3 bara steam in the flash tank, and the amount of steam produced in the FT is calculated for a temperature difference of 5 K in the absorber.

The steam pressure level set in the flash tank influences the selection of the thermocompressor, which needs to consume a certain amount of HP steam in order to produce the required medium pressure level.

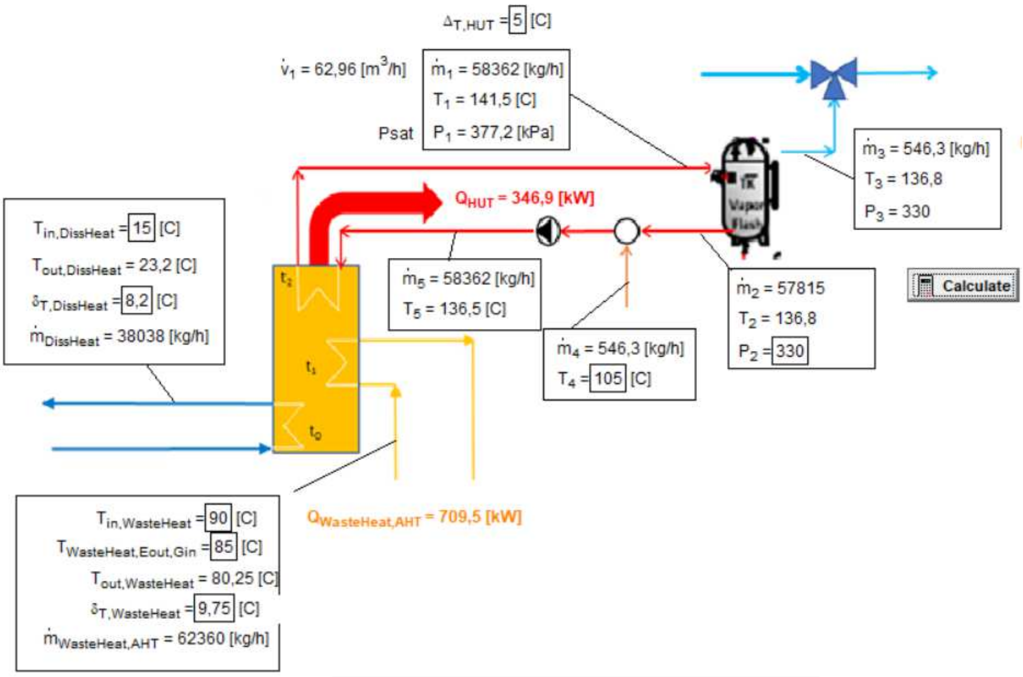

Figure 9. Thermodynamic model of AHT + flash tank in EES.

With the defined nominal conditions of AHT, its complete design has been developed among BS Nova (manufacturer), TU Berlin and Tecnalia. The Steam generation module has been designed by sizing the flash tank, thermocompressor and the rest of auxiliaries.

- The calculation of the flow rate of motive steam that is necessary for the pressure increase has been calculated by means of selection software of the thermocompressor manufacturer company Baelz. and has been used to select the size of the corresponding ejector. The resulting flow rates and characteristics of the ejector are included in Table 1 and Figure 10.

Table 1. Main characteristics of the selected thermocompressor

Termocompressor selection for Demo 3		
Manufacturer / Model		Baelz /Steam Jet Pump 590
Nominal ejector diameter	DN	65
Nozzle diameter	mm	19.2
Suction stream (lowest pressure)		
Pressure	bar(a)	3.3
Mass flow rate	kg/h	540
Motive stream (highest pressure)		
Pressure	bar(a)	14.5
Mass flow rate	kg/h	2 046
Discharge stream (intermediate pressure)		
Pressure	bar(a)	6.5
Mass flow rate	kg/h	2 586

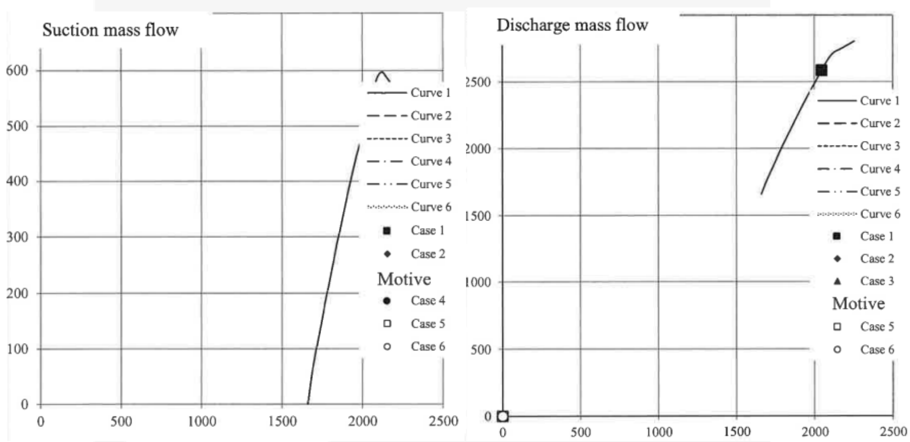

Figure 10. Thermocompresssor characteristics (from manufacturer calculation)

3.2. Design parameters of the Heat Upgrade System

Table 2 summarizes the main characteristics of the heat upgrade system for the design conditions (maximal expected heat upgrade). As can be observed in the table, electrical and thermal efficiency KPIs are defined. These KPIs are referred to the AHT with the typical definition for thermal COP (Upgraded heat/Waste input heat), and also at system level, taking into account that in this case the rejection heat of the condenser is also useful heat (Absorber heat+Condenser heat/Waste input heat).

Table 2. Main nominal characteristics of the heat upgrade system

Heat Source design parameters		
Parameter	unit	value/information
Thermal capacity for driving AHT	kW_{th}	709
Flow rate	m^3/h	64.5
Inlet temperature evaporator	°C	90
Outlet temperature desorber	°C	80.3
Heat transfer fluid	-	water
High Temperature Heat Sink design parameters (useful heat)		
Thermal capacity	kW_{th}	347
Flow rate hot water circuit 2	m^3/h	63
Inlet temperature absorber AHT	°C	136.5
Outlet temperature absorber AHT	°C	141.5
Fluid circuit 2	-	pressurized water
Mass flow rate Flash Tank steam (s1)	Kg/h	540
Pressure Flash Tank Steam (s1)	bar(a)	3.3
Flow rate TC motive steam (s0)	Kg/h	2 046
Pressure TC motive Steam (s0)	bar(a)	14.5
Flow rate TC discharge steam (s2)	Kg/h	2 586
Pressure TC discharge steam (s2)	bar(a)	6.5
Low Temperature Heat Sink design parameters (heat rejection)		
Flow rate	m^3/h	38
Inlet temperature condenser	°C	15
Outlet temperature condenser	°C	23.2
Fluid circuit 0	-	cooling water from the river
Absorption Heat Transformer unit (single effect)		
Electricity consumption*	kW_{el}	4.3
Coefficient of Performance AHT (COP_{el})*	kW_{th}/kW_{el}	347 / 4.3 = 80.7
Coefficient of Performance AHT (COP_{th})	kW_{th}/kW_{th}	0.49
Coefficient of Performance system (COP_{el})*	kW_{th}/kW_{el}	709 / 4.3 = 164.9
Coefficient of Performance system (COP_{th})	kW_{th}/kW_{th}	1
Refrigerant / solution	-	H_20 / LiBr aqueous solution

* Considering only internal pumps and control of the AHT unit

Funded by the European Union

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

3.3. Control concept and control integration

The main function and boundary conditions for the operation of each of the components can be described as follows, referring to the different circuits marked in colours in the previous scheme (Figure 8).

- In the heat rejection circuit (Heat Rejection circuit (0)) the pipes are connected to the water circuit (river water) on one end and to the condenser of the AHT on the other end. Because the pressure at this circuit is sufficiently high (>2 bar) there is no need to include an additional pump. A 2-way valve flow control valve is the only relevant active component within this circuit.
- The driving heat circuit (Waste heat circuit (1)) is a closed one and connects the heat source line (common heat source for Demo 2 and Demo 3) and the generator and evaporator of the AHT. The heat recovered from the industrial process is the heat transferred to the cooling water of the cogeneration plant.
  The hot water from the cogeneration plant will be pumped in a common line to both Demo (2 & 3) circuits. A 3-way valve will be used to feed the AHT with the waste heat (in series, first entering the evaporator and then the generator).
- In the Upgraded heat circuit (2) pressurized hot water at a temperature level between 136.5 ºC and 141.5 ºC circulates between the absorber of the AHT and the flash tank of the steam generation module. In the flash tank (FT) a small amount of the large pressurized hot water flow evaporates. The amount of water that evaporates depends on the difference between the temperature of the hot water entering the flash tank and the steam pressure inside it in steady state. This temperature difference is the same as between absorber inlet and outlet. The ratio of evaporated steam in the tank increases with this temperature difference, but as trade-off the heat upgrade capacity of the AHT decreases with increasing temperature difference.
- A design compromise has been found by fixing the temperature difference at the absorber at 5 K, prioritizing in this way the AHT heat capacity per heat transfer area over the ratio of evaporated steam. Consequently, for the operating design conditions for the flash tank at around 3.3 bar(a), the percentage of flash steam formed in the tank is around 0.9 %. For the operating conditions of the AHT fixed for the selected operation case that results in a water flow rate of 63 m^3/h and a steam flow rate of 540 kg/h.

Funded by the European Union

- **In the steam circuit (s)** the steam produced at a pressure around 3.3 bar(a) in the flash tank **FT** is increased to a pressure level of 6.5 bar(a) by means of the thermocompressor **TC**. In the thermocompressor or steam ejector, motive steam at a higher-pressure level of 14.5 bar(a) is used to perform this pressure upgrade. The calculation of the flow rate of motive steam that is necessary for the pressure increase has been calculated by means of selection software of the thermocompressor manufacturer company Baelz and has been used to select the size of the corresponding ejector.

The initial basic control concept has been defined within the basic engineering phase. This initial control integration scheme determines the main active components that are necessary for the operation and part-load regulation of the HUT system.

The so called "DDt-control" module, integrated in the HUT control unit and developed within the frame of this project by TU Berlin assisted by Tecnalia, will control the pumps and valves of the system in order to have the best combination of external heat carrier flow rates and inlet temperatures to the AHT at each of the three external circuits in order to have the minimal possible electrical consumption of the external pumps when providing steam at the required pressure, that will be the set value for the HUT control system.

- In the **Heat Rejection circuit (0)**, the flow rate of cooling water will be controlled by means of a control valve. There will be no possibility for inlet temperature control at the heat rejection circuit.
- In the **Waste heat circuit (1)**, the total flow rate of hot water circulating through the generator and evaporator and the AHT, will be controlled by a three-way-valve.
  Different alternatives were studied for the waste heat circuit (or driving heat circuit of the AHT), a configuration in parallel to the generator and the evaporator, or a configuration in series. Finally, the series configuration was chosen, having the advantage of lowering down the external electrical energy consumption for circulation of the hot water (improvement of the electrical COP).
- In the **Upgraded heat circuit (2)** the flow rate of hot water will be controlled by a pump. The governing pressure at the flash Tank FT will determine the temperature of the hot water entering the absorber of the AHT. The pressure at the flash tank is coupled with the operation of the thermocompressor TC, as described below. Additionally, the maximal pressure within the flash tank is controlled using relieve valves that will open if the

pressure at FT arises over a certain boundary. This will only happen if the TC is not on operation.

- In the **Steam circuit (s)**, low-pressure steam produced in the flash tank will go through the turbocompressor. When the turbocompressor is in operation, it will let steam at the higher-pressure level s0 flow through, reducing its pressure to a medium-pressure level s2 and sweeping along steam at the lowest pressure level s1.
- During start up of the HUT or in case of malfunction of the AHT unit, the pressure level at the flash tank will be below its nominal value. Below a certain pressure level, no steam at the lowest pressure level will be dragged, and the thermocompressor will act as a reduction valve if it is open. For the start-up however the thermocompressor will be kept closed until the pressure level at the flash tank reaches Its nominal value. At this point the thermocompressor will start its operation. In normal operation, an electrically driven motor within the termocompressor keeps the discharge pressure at a certain set level by changing the nozzle opening and its effective diameter. The control loop will be integrated within the HUT control unit, together with the DDt-control of the AHT.

3.4 Monitoring concept

A selection of the necessary measurement equipment that will be included with the HUT system has been made, taking into consideration the initial control concept presented in the last section and the performance analysis that will follow within the project. With all the measured variables, a set of Key Performance Indicators (KPIs) will be calculated. The KPIs will be calculated taking into account different boundaries:

1. Heat upgrade technology (HUT).
2. HUT + primary circuits (PC).
3. Heat upgrade system.
4. Overall system (HUT + PC + external generator with distribution system).

Main KPIs which will be calculated include:

- Electrical COP
- Thermal COP

Funded by the European Union

- Primary energy efficiency
- Fuel, electricity, primary energy and CO_2 emissions variations before and after HUS installation and operation.

For the monitoring concept, some of the sensors and instruments will be part of the integration circuits of the HUT, and others will be delivered together with AHT by the technology provider. Additionally, the instrumentation equipment necessary for the steam production module is considered separately. Inlet and outlet temperature as well as pressure sensors will be included in all the external circuits of the AHT (absorber, evaporator, generator, condenser). Additionally, heat flow meters which also include temperature probes, are included in the three circuits:

- Upgraded heat circuit (2)
- Waste heat circuit (1)
- Rejection circuit (0)

Two of the three steam lines (the low-pressure steam line and the medium-pressure steam line) will include temperature, pressure, and flow measurement to calculate the steam produced both in the flash tank and in the turbocompressor.

With the previously mentioned measured variables, the heat flows of the different circuits can be calculated. Additionally, electrical measurements will be made, comprising:

- AHT electrical consumption
- Upgraded heat circuit pump electrical consumption.
- Waste heat circuit pump (common to both Demo 2 and Demo 3) electrical consumption.

These measurements will provide essential data to calculate key performance indicators (KPIs) such as COP (Coefficient of Performance), SPF (Seasonal Performance Factor), PER (Performance Efficiency Ratio), and more. These KPIs will help assess the efficiency and effectiveness of the Heat Upgrade System.

Funded by the European Union

4. Conclusions

This document presents the application Case selected for integrating the Push2Heat project absorption heat upgrade technology within the paper plant of the company Cuartiere di Gaurcino in Lazio (Italy).

After analyzing the plant's current energy production and consumption conditions and the availability of waste heat, the basic design of the Heat Upgrade System has been carried out. The most suitable combination of absorption heat transformer and steam generation module has been selected, as have the nominal conditions in each of the streams.

The report describes this process and the components necessary for integrating the heat upgrade system within the plan and presents the preliminary control and monitoring concept.

Funded by the European Union

REFERENCE LIST

- PUSH2HEAT PROJECT. Project Deliverable: D2.2 Demonstration site at CdG – System design.
- PUSH2HEAT PROJECT. Project Deliverable: D2.6 Techno-economic map of Heat Upgrade Technologies. https://doi.org/10.5281/zenodo.12607323
- S. A. K. Keith E. Herold, Reinhard Radermacher, Absorption chillers and Heat pumps (2nd edition). 2016.
- Klein, S. (2022, 09 22). EES - Engineering Equation Solver. *Version V10*. F-Chart Software
- Jose L. Corrales Ciganda, Falk Cudok. Performance evaluation of an absorption heat transformer for industrial heat waste recovery using the characteristic equation. Applied Thermal Engineering Volume 193, 5 July 2021, 116986.

Funded by the European Union