Low valued energy sources UPgrading for buildings and industry uses

# Case Studies Description

## Deliverable D3.1

**Lead Beneficiary: FUNDACIÓ EURECAT**
**04/2017**

**Josep Pijuan[1], Mario Heredero[1], Silvio Vitali Nari[2]**

[1] *Fundació Eurecat*
[2] *ACCIONA Construcción S.A. R&D Centre*

http://www.lowup-h2020.eu

The LowUP project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement n°723930.

## Document Information

Grant Agreement: 723930

Project Title: Low valued energy sources UPgrading for buildings and industry uses

Project Acronym: LowUP

Project Start Date: 1 November 2016

Related work package: WP 3: Industrial low temperature energy upgrading solutions

Related task(s): Task 3.1: Resources assessment and feasibility for case studies

Lead Organisation: EUT

Submission date: 28/04/2017

Dissemination Level: Public

## History

| Date | Submitted by | Reviewed by | Version (Notes) |
|---|---|---|---|
| 04/04/2017 | Mario Heredero | Silvio Vitali | V 0.1: Table of Contents and first material. |
| 21/04/2017 | Mario Heredero | Josep Pijuan, | V1.0: First version of case studies without images |
| 26/04/2017 | Mario Heredero | Josep Pijuan | V 1.3: Added content to objectives, challenges, images, included contributions from Acciona |
| 27/04/2017 | Mario Heredero | Josep Pijuan | V 1.4: Added case studies, executive summary and conclusions |
| 28/04/2017 | Josep Pijuan | Jose C. Esteban | V 1.6. Final version |

## About LowUP

LowUp – Low valued energy sources UPgrading for buildings and industry uses – is developing efficient alternatives to supply heating and cooling for building and industries, based on the use of renewable free energy and heat recovery from non-valuated residual energy sources that are currently wasted. As a result, these technologies will contribute to reducing significantly $CO_2$ emissions and primary energy consumption, and increasing the energy efficiency in buildings.

Led by the Spanish firm ACCIONA, the LowUp project gathers 13 partners (3 large companies, 3 research and technology organisations and 7 SMEs) from 7 European countries. During 42 months, the consortium will develop efficient alternatives to supply heating and cooling for buildings and industries based on renewable free energy as well as non-valuated wasted thermal sources:

- 3 technologies will be developed and demonstrated: one heating and one cooling system for buildings, and one heat recovery system for industrial processes.
- The systems will be demonstrated at 4 demo sites: a water treatment plant (ACCIONA) in Madrid, a test facility (ACCIONA) in Sevilla, an automotive factory and a retirement home.

*For more information visit: www.lowup-h2020.eu*

**Coordinator contact**
Jose C. Esteban Matías
Acciona Construcción S.A.  R&D Centre
C. Valportillo II, 8, 28108 Alcobendas (Madrid, Spain)
email: josecarlos.esteban.matias@acciona.com

# Table of Content

## Tables



## Figures

## Executive Summary

LowUP project aims to define, develop and demonstrate different system solution for low valued energy recovery in the building and industrial sector. The main objectives of this first public report is to describe the most suitable case studies for the development and validation of the LowUp project, focused on the low temperature heat recovery in industrial environment.

With that purpose, HP-LowUP, the third of the three system-technologies to be developed during the LowUP project lifespan, is presented and its main challenges and objectives are pointed out. In this case, the system is oriented for industrial applications, where it can provide part of its heating demands thought the use of self-cleaning heat exchangers and heat pump technology that take advantage from dirty flows (around 20 -30 ºC) currently wasted. The two previous technologies, HEAT-LowUP and Cool-LowUP are devoted to the supply of space heating and cooling in buildings.

This report includes the analysis and description of the most promising industrial processes in terms of low temperature waste heat resources, heat demand, as well as the identification of the necessary information to be monitored in order to characterize the energy availability and the operation boundaries of the LowUP system. So far, (1) anaerobic digestion in wastewater treatment plants, and (2) car body coating process, in the automotive industry, have already been identified as interesting case studies for the application of the HP-LowUP concept. Originally, those "case studies" were identified as the most promising and suitable ones; but during this first stage of project life, when there has been lot of activity to prepare the next stage of demonstration of the HP-LowUP system (in the context of WP4), that imply to assess possible layout and gather features from the demonstration sites. It has brought us the chance to assess different real industrial facilities, even in different sectors from formerly proposed, as the paper making industry.

Moreover, the methodology defined by the consortium for the definition, development and demonstration of the HP-LowUP concept is described.

The expected results present that the HP-LowUp concept has a great potential of application and replicability in the industrial sector in many other cases, due to its compatibility with multiple processes that produce low temperature wasted energy. On the other hand, the recovery of low exergy increases the flexibility and efficiency in the operation of the industrial processes, as well as the sustainability, energy independence and resilience of the EU industrial sector.

## Keywords

Waste heat recovery, low-temperature waste heat, heat pump technology, low-valued energy systems, low exergy systems, energy efficiency, industry, case studies

# 1 Introduction

LowUP "Low valued energy sources UPgrading for buildings and industry uses" project has the objective to study and to develop innovative technology solutions that permit to take advantage of low valued energy, available in waste sources, and apply it for heating and cooling processes.

Low valued energy, also defined as low exergy, is energy which has a very limited convertibility potential into other types of energy (electricity, mechanical workload, etc.), such as heat source close to room air temperature. The smaller the temperature difference the bigger the surfaces for delivering energy. Low exergy heating and cooling systems are defined as heating and cooling systems that allow the use of low valued energy as the energy source. In practice, this means systems that provide heating or cooling energy at a temperature close to room air temperature. LowUP project is focused on both the tertiary and industrial sector, developing different solutions of low exergy heating and low exergy cooling, which will be adapted to each application case in terms of energy availability and operation conditions.

The origin of the LowUP concept is directly linked and based on the European Union recent framework strategy [1] and on the "Secure, clean and efficient" Horizon 2020 Work Programme 2016-2017 [2]. Specifically, the following reasons motivated the LowUP concept:

A. The growing necessity for an increase in the efficiency of using the different available energy sources is obvious and indisputable. In buildings, heating and cooling appliances, together with lighting, are responsible of a third of the world's primary demand (ECBCS 20) and in Industry there are processes where from 20 to 50% of the energy consumed is ultimately lost via waste heat when captured and reused waste heat is an emission free substitute for costly purchased fuels or electricity.
B. The need of increasing the share of low valued energy sources in the supply of useful heat and cooling by using low exergy systems at temperature levels close to room temperature for space heating (21ºC) and cooling (24ºC) applications. The increase of well insulated new building and renovation due to European Directives will promote the use of low exergy systems more affordable for low heating and cooling demand.
C. Up to 30% of the energy we use every year is expended to heat water and therefore later goes down the drain. As energy-efficiency regulations for buildings grow stricter, the energy contained in hot water will come to account for more than 50% of buildings' thermal balance.
D. The lack of proved solutions for heating and cooling in buildings using low grade sources of thermal energy and validated technologies for upgrading low temperature resources in industrial processes coming from non-used low temperature heat flows.
E. The need of cost-effective heating & cooling solutions able to make the market more attractive for energy savings

LowUP project is tackling with three different systems, which will be developed and demonstrated in a relevant environment:

- HEAT-LowUP: Low exergy heating system directly fed by solar and sewage water recovered heat
- COOL-LowUP : Low exergy cooling systems directly fed by renewable and free energy sources
- HP-LowUP: Waste heat recovery and upgrading via heat pump.

First and second ones are focused on the rational and efficient use of low valued energy sources for direct implementation in low-exergy heating and cooling systems for buildings (HEAT – LowUP and COOL – LowUP), while the third one is focused on the exploitation of low temperature residual wasted energy of industrial processes, by recovering it to generate useful heat that is re-introduced into the system (HP –LowUP).

This document is focused on the description of the proposed **HP- LowUP** technical approach and the analysis of possible "case studies" for demonstration of this HP-LowUP system de envisaged during the project (next WP4 Demonstration and Validation), and the introduction of this "case studies" as earliest sources for replication and exploitation (WP5 Exploitation, Dissemination and Communication).

## 1.1 HP-LowUP

The HP- LowUP concept is based on an effective and reliable heat pump based system, and 100% thermal powered by residual and rejected low temperature energy sources (below 45ºC), for application at industrial processes with temperatures up to 80 ºC. This temperature upgrading solution is based on the combination of heat recovery technologies, from low valued energy sources like rejected and process waste heat (20-45ºC), with high efficiency-high temperature water-to-water heat pump for the production of process heat between 55-80ºC. Ammonia based compressor will allow the heat pump cold sink operating at higher temperature than traditional HP; the heat pump is powered by electricity but the performance expected is very high: the COP[1]envisaged is higher than 6. On other hand, the self-cleaning heat recovery system will allow to recover efficiently heat from high density-viscosity fluids. By this way, it is possible to re-cycle part of the heat used in the light industrial process that would be normally dissipated, reducing the use of fossil fuels (natural gas, electricity, flue, etc…).

Moreover, an advanced control system, based on the demand prediction and the availability of resources, will allow to generate operation strategies suitable for extend HP lifetime and number of hours of operation, maintaining high efficiency during partial loads. Finally, a supervisory control system will monitor the system detecting performance anomalies in the system and predicting maintenance actions when needed.

As shown from the Figure 1, HP-LowUP system is composed by the following technologies:

- A sludge/wastewater-to-water or water-to-sludge/process water heat exchangers that could be used as a heat recovery system or as a heat delivery system.
- High efficiency electrically driven heat pump.

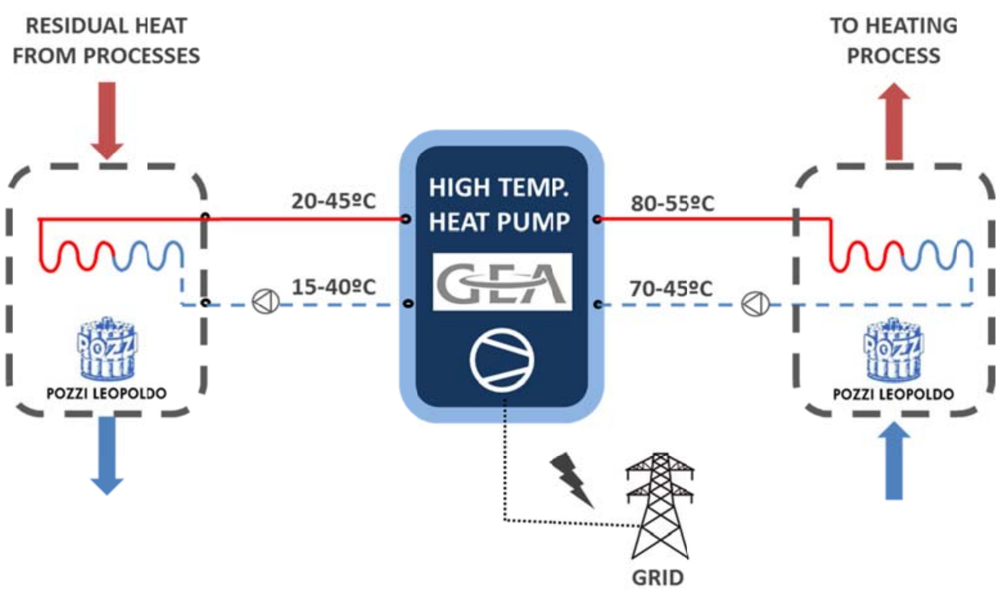



**Figure 1: HP-LowUP concept**

[1] COP Coefficient of Performance: number of Heat units produced by every Electricity unit used.

## 2 Challenges of the HP - LowUP concept

Many processes in industry are producing large amount of waste heat, much in the low-temperature range, at the same time they have large heating demand and cooling demand (Lemmens, 2015; U.S. Department of Energy, 2008; [17.]). Among all suitable industrial processes with described requirements, the most interesting processes have been identified in section 4 and two of them have been initially selected for the demonstration of the project.

The common heat recovery systems for industry are used to recover waste heat at temperatures from 100ºC to 500ºC. These systems use technologies such as Organic Rankine Cycle (ORC), absorption chillers and steam generators, to recover the heat from the industrial processes and transferring heat to other processes, or generating mechanical or electrical power. However, there are many processes working with lower temperatures in the range between 20-200ºC that can be also targeted through the integration of other systems based on heat exchangers and heat upgrading technologies, like heat pumps. The lower the temperature, the higher the technological level necessary for make this residual heat useful.

As an example, in many processes, cooling and heating demands are individually covered, without a fully integrated production layout of heating and cooling needs. This leads to wasteful energy flows in which hot water is cooled by chilled water to achieve the required temperature. We also see many processes with large heating demand at high temperature (e.g., 80°C for pasteurization) and large cooling demand at low temperature (2°C chilled water) – both of which lead to considerable waste heat at medium temperature (35 - 60°C). Production regimes that generate waste water at 35 to 60°C often use cooling towers to cool this water before sending it to the sewage system: commonly, legislation limit the maximum temperature (around 30°C) of waste water allowed to enter the sewer. The cost of running these cooling towers can be saved by generating useful heat from the waste heat. The carbon savings and return of investment on waste heat recovery heat pumps can be very attractive, but this all depends on the efficiency of the heat exchangers and the heat pump.

On other hand many low temperature fluids outcoming from productive processes contain suspended material, organic or not, which must be treated before disposal or before a potential heat recovery because of the problems of fouling that can be faced with traditional technology. In fact most of the commercial equipment, heat pumps included, is designed for operating with clean water as heat transfer fluid, in order to reduce maintenance problems and maintain stable the heat exchange factor. The suspended contaminants of the fluid can be present in different concentrations, with different heat capacity from effluent, generating lack of efficiency reliability during operation, exposing high level technology to risk of failure, increment of maintenance costs, redundancy of equipment and unplanned stops. The introduction of a robust and efficient heat recovery solution would transform a problem of treatment and disposal into a heat source potential, a by-product cost into an energy saving.

In brief, the large quantities of available waste heat in the range of 20-200°C, and the inherent challenges to its recovery and use, warrant a separate and in-depth investigation of low valued waste heat recovery [17.]. Low valued energy recovery and application faces at least three main challenges:

- Low valued energy recovery from non-water streams (sludge, paint, corrosive fluids, etc.). Those fluid streams present a complexity when heat is recovered via heat exchanger due to fouling and scaling problems and due to the small temperature gradient, which requires larger surface areas for heat transfer. These facts limit the economics of heat exchangers. The same complexity exits when recovered heat is transferred to non-water stream as a way to fulfil the demand of some industrial processes.
- High efficiency heat upgrading technologies, such as heat pumps, with the capacity to upgrade heat to a higher temperature, in order to serve a load/process requiring medium temperature.

  These technologies will widen the options so as to use the low temperature recovered heat in more applications which require a higher temperature.

- Advanced supervisory control system for reliable, efficient and automated operation of the whole systems adapted to the requirements of the industrial processes. The control should adapt the system load to the demand and the residual energy profiles of the site by its monitoring and analysis of the data. In case of any anomaly or malfunction of the system it should provide the right recommendations to the operators, scheduling maintenance actions or apply the appropriate contingency plans.

The main breakthrough of the HP-LowUP solution proposed is the development, manufacturing and testing of one sludge/wastewater-to-water heat exchanger connected to a water-to-water heat pump prototype; the final target is producing higher temperature level of the useful heat (up to 80ºC), being able to take benefit of low temperature levels of free heat sources (25-35ºC) from waste heat in industrial processes.

# 3 Objectives

The main objective of the HP – LowUP system is the research and analysis of residual energy resources, and the development and validation (at component and system levels) of an energy recovery solution, for heating in industrial processes. All planned R&D activities will lead to overcome actual limits of operation/integration, and to improve specific efficiency of each technology and global performance for the whole system, targeting actual payback periods, and challenging with traditional fuel-based technologies. In addition, an advanced control system and a supervisory control will allow the autonomous and efficient operation of the system facing any anomaly and preventing the appropriate maintenance actions.

Particularly the main technical objective of HP – LowUP is to achieve COP>6 with a temperature lift of 35K, with constant temperature in the hot sink independently from the availability of the cold sink, by the improvement of the heat exchanger technologies involved in the capturing energy flows and the efficiency of heat pump.

The expected result is the development of an integrated concept able to compete, in the production of processing heat, with traditional industrial boilers in terms of efficiency, consumption of primary energy, GHG emissions and operation cost.

The following table shows a summary of the expected project results:

**Table 1 : HP- LowUP summary of objectives**

| System | Objective |
|---|---|
| Waste water heat recovery system | o Self-cleaning fouling free heat exchanger.<br>o Increase heat exchanger efficiency over 70% |
| High efficiency electrically driven heat pump | o 100% thermal powered system<br>o Recovery of waste heat at 20-45ºC<br>o Production of process heat up to 80ºC<br>o Seasonal COP over 6 (10% more efficiency than conventional heat pump).<br>o Temperature lift of 35ºC |
| Control and maintenance | o Advanced control system based on optimization and heat demand and availability forecast<br>o Supervisory control for maintenance and surveillance |
| Expected system investment | o CAPEX between 400-500 €/kW |
| Global system impact | o Between 45 and 70% of expected GHG emissions saving (compared with a conventional system).<br>o Between 20 and 55% of expected primary energy saving (compared with a conventional system). |

The development of the HP-LowUP system and/or its sub-systems, and the test to be performed to validate the achievement of these objectives (in the context of LowUP WP 4), will consider always the possibilities and best practices in order to reach a future exploitation of these results of the project. Further analysis of the exploitation interests are being developed in the context of the WP5 of the project.

# 4 Case studies

Evaluating the feasibility of waste heat recovery requires characterizing the waste heat source and the stream to which the heat will be transferred [17.]. Important waste stream parameters that must be determined include:

- Heat quantity: It describes how much energy is contained in a waste heat stream.
- Heat temperature/quality: This parameter is a measure of the usefulness of the waste heat. The waste heat temperature is a key factor determining waste heat recovery feasibility. Exergy is another variable used so as to characterize the quality of energy.
- Composition: Composition of the waste heat stream (liquid, steam, etc.) and its characteristics (density, viscosity, dirtiness, etc.)
- Minimum allowed temperature: Temperatures required for waste heat recovery and application.
- Operating schedules, availability, and other logistics.

These parameters allow for analysis of the quality and quantity of the stream and also provide insight into possible material, technology and design limitations. For example, corrosion of heat transfer media or heat exchanger fouling resistance are of considerable concern in waste heat recovery, even when the quality and quantity of the stream is acceptable.

HP – LowUP concept main target are the low temperature (low exergy/quality) waste heat source in industry (between 35 - 60ºC) so as to upgrade and apply this energy in a higher temperature (higher exergy/quality) application. Based on a previous analysis regarding the industries with availability of low exergy waste heat and low exergy cooling and heating demand, two main industrial uses will be focused on the project:

- Wastewater treatment plants, exploring the viability of capturing low temperature heat from digested sludge and upgrading with high efficiency heat pump for reducing the contribution of gas boilers to the heating of the anaerobic digester or for drying sludge before landfill.
- Automotive factories, exploring the viability of capturing heat from sewage flows coming from painting and washing stations, as well as exhaust heat of the cooling towers, and upgrading it up to usable temperatures via heat pump for implementation into industrial processes.

Other industrial processes have also been identified so as to help the future exploitation analysis that will be done during WP5.

In the following sections, a deeper insight into those industrial processes will be carried out so as to better understand them and correctly define the development and demonstration of the HP – LowUP concept.

## 4.1 Case study 1: Wastewater treatment plant

Wastewater treatment is a process used to convert wastewater, which is water no longer needed or suitable for its most recent use, into an effluent that can be either returned to the water cycle with minimal environmental issues or reused. The physical infrastructure used for wastewater treatment is called a wastewater treatment plant (WWTP); see an example in Figure 2.

**Figure 2: WWTP overview in Pinto, Spain. Source:** (Canal de Isabel II, 2008)

WWTP process, presented in Figure 3, is based on three main sub processes (Metcalf & Eddy, Tchobanoglous, Burton, & Stensel, 2002).

- Preliminary treatment: In preliminary treatment, gross solids such as large objects, rags, and grit, which could damage the equipment, are removed.
- Primary treatment: In primary treatment, physical operation, usually sedimentation is used to remove floating and settle able materials found in wastewater.
- Secondary treatment: In secondary treatment, biological and chemical processes are used to remove most of the organic matter.

In advanced treatment, addition processes are used to remove residual suspended solids and other constituents that are not reduced significantly by conventional secondary treatment.

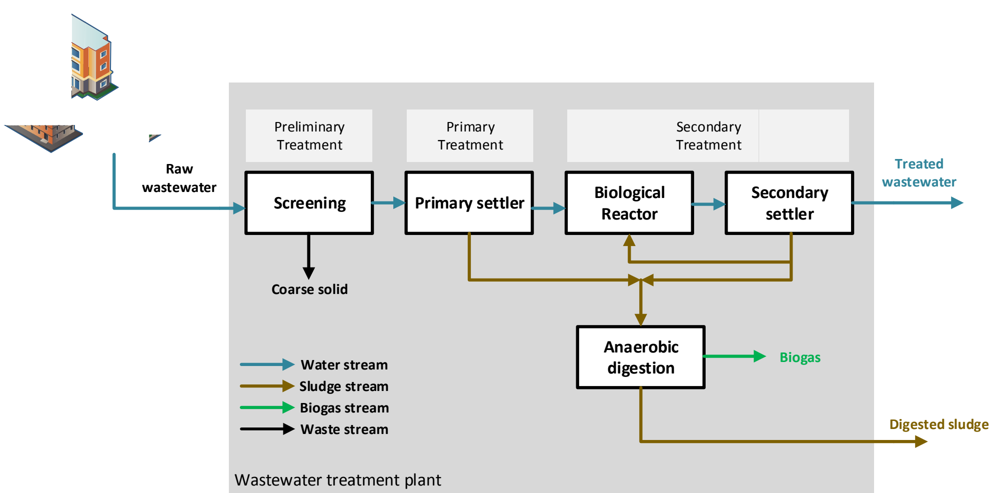



**Figure 3: Schematic illustration of a typical wastewater treatment plant.**

The sewage sludge produced in wastewater treatment plant, as by -products from the primary and secondary treatments, requires to be treated. Anaerobic digestion (AD) is a proven technology for sewage sludge treatment because it allows a high reduction of the solid matter in the sludge while it allows the generation of renewable energy from the same process

In general, sludge is composed by easily degradable organic matter, from the primary treatment, and also by excess sludge or activated sludge from the secondary treatment. Greases from the grease trap (usually found at the entrance of the plant) are often also digested. Screenings are not suitable for AD as they contain coarse materials that may be harmful to pumps and stirring systems. The sewage sludge resulting from primary and secondary water treatment is gathered for AD. Before entering the digesters, the sludge is sometimes sieved and is then thickened to a dry solids content of up to 7% in order to avoid too high energy consumption for heating due to excessive water content (Bachmann, 2015).

The sludge is pumped into the anaerobic continuously stirred tank reactors (CSTR), see Figure 4, where digestion takes place, usually at mesophilic temperature (35 – 39 °C). During a retention time of around 20 days, microorganisms break down part of the organic matter that is contained in the sludge and produce biogas, which is composed of methane, carbon dioxide and trace gases. At the same time, the sludge is stabilised and its dry matter content is also reduced (Bachmann, 2015).

The benefits of AD of sewage sludge are widely recognised and the technology is well established in many countries. Today, a high portion of biogas produced in AD plants is from those on municipal wastewater treatment sites and there is still an enormous potential to exploit worldwide so as to treat organic waste in decentralized sites. Currently less than one percent of the potential benefits from AD are being used (EUBIA, 2016).

**Figure 4 Anaerobic digesters in Pinto, Spain .Source:** (Canal de Isabel II, 2008)

Next sections, the suitability of this case study to implement the HP – LowUP system are detailed.

### *4.1.1 Low exergy waste heat availability: Anaerobic digester*

After the anaerobic digestion, the digested sludge is released at a constant temperature around 35ºC so as to be dewatered. At this point, the remaining low exergy heat contained in the sludge will be recovered. HP – LowUP will allow to avoid the exergy loss occurred when the sludge is cooled down during the following process of storing and dewatering. Figure 5 shows the sludge effluent pipes where sludge is transferred to the dewatering process.

**Figure 5 Digested sludge effluent pipes. Source:** (Canal de Isabel II, 2008)

### *4.1.2 Low exergy heat demand: Anaerobic digester*

The anaerobic digestion requires a constant temperature of 35ºC in order to accelerate biological conversion. The thermal process of sludge heating is commonly achieved via water-to-sludge heat exchanger, where heating can be provided from combined heat and power (CHP) and boilers, producing water at 70ºC; the heat exchangers have an exchanging capacity between 200-500 kWth.

### *4.1.3 Analysis of HP-LowUP application in the wastewater treatment sector:*

First of all, low temperature heat (30ºC) will be recovered from the digested sludge pipes through the new heat exchanger developed and constructed by POZZI, see Figure 5. Then, recovered energy will be upgraded to a higher temperature (60ºC), by the use of the developed electrically driven heat pump from GEA, in order to be reuse it in the heating system of the the AD. HP – LowUP will be used so as to improve the efficiency of AD by reducing the amount of energy required so as to maintain the conditions that allow a proper anaerobic digestion and biogas generation.

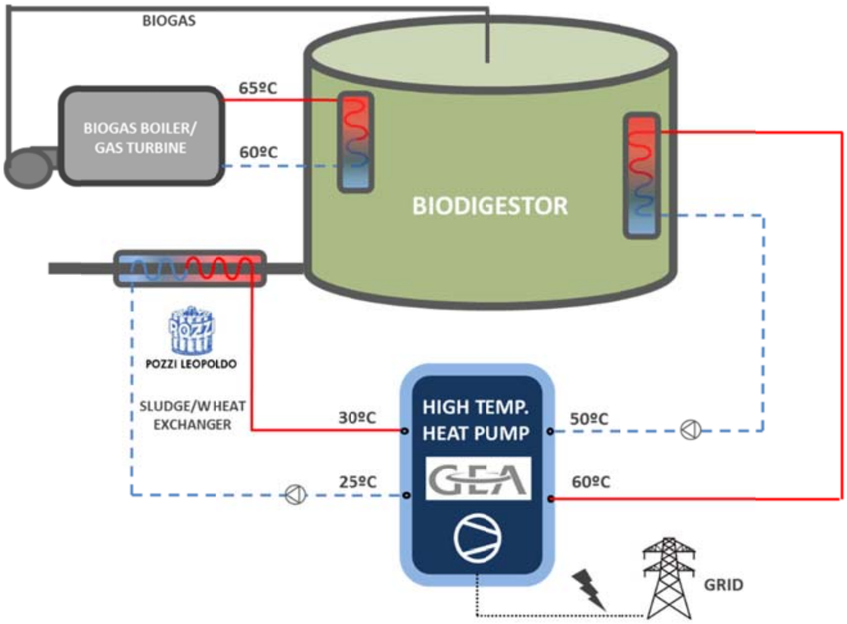



**Figure 6 HP-LowUP concept applied in the anaerobic digester.**

An estimated characterisation of the demonstration site is shown in the following table.

**Table 2 Information about case study 1 (estimated per 6.500m3 digester). Source:** (Bachmann, 2015)**,** (EUBIA, 2016)

| General information | | |
|---|---|---|
| Process | Anaerobic digester | |
| **Waste Heat availability** | | |
| Type of Water | Digested sludge | |
| Temperatures (average) | 35.3 | ºC |
| Flow (average) | 53 | $m^3$/day |
| Operation profiles | 24 | h/day |
| Waste heat availability | 12.8 | kW |
| **Heat demand** | | |
| Temperatures (average) | 60 | ºC |
| Heat demand (maximum Power of heat exchangers) | 530 | kW |
| Demand profiles | 24 | h/day |
| **Expected Impact** | | |
| Increase in the overall efficiency | 40 | % |
| Primary energy Savings | 22 | % |
| CO2 Emissions reduction | 48 | % |

Based on the gathered information, AD fulfils the requirement so as to become a case study and demonstration site for the HP-LowUP concept. Waste heat and heat demand temperatures are between the ranges of HP-LowUp concept. Moreover, it must be pointed out that the amount of the possible heat recovered, which is now of 13 kW but could generate up to 78 kW due to the expected COP of the heat pump, must not be underestimated compared to the maximum power of the current heating system heat exchanger, which is between 200kW and 500kW.

### *4.1.4 Analysis of HP-LowUP replicability in the wastewater treatment global market:*

Now, about 71,000 municipal wastewater treatment plants (WWTPs) are in operation in the 28 EU member states, Iceland, Norway and Switzerland. Many of them do not only treat municipal wastewater, but also organic polluting loads of connected commercial operations. The total treatment capacity of the WWTPs amounts to about 775 million population equivalents (Business Wire, 2013).

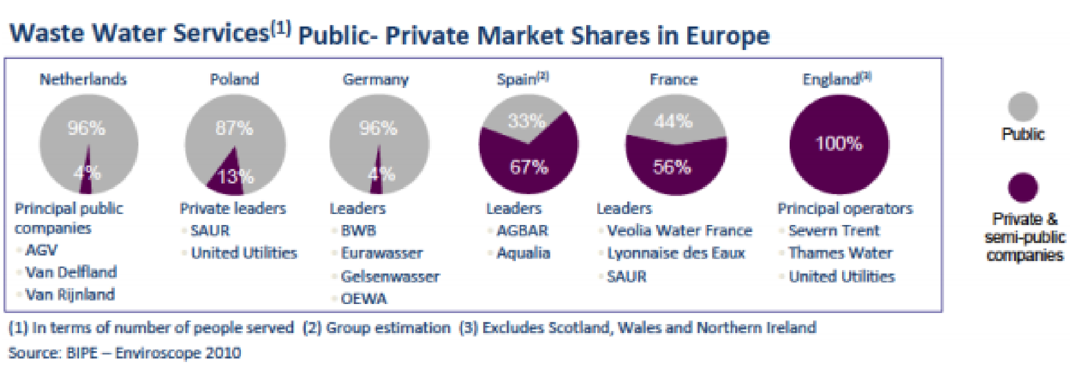



**Figure 7: Waste Water Services in Europe – Public Private market share. Source:** (UrbanWater Consortium, 2013)

The market for municipal wastewater treatment plants will continue to grow in the long term in Europe. Over the past 20 years, the number of municipal wastewater treatment plants has increased steadily while their technical standard improved. Germany is the largest national market in Europe, it accounts for almost 20% of the total share in Europe. The treatment capacities installed in the country amount to 145 million population equivalents. In addition, the largest number of plants can be found in France, where more than 19,000 municipal wastewater plants are located (Business Wire, 2013).

The sector is expected to grow worldwide. Some of the megatrends that are pushing the development of wastewater plants are: energy efficiency improvements of the systems, biogas generation from wastewater treatment, Chemical free water & wastewater treatment, etc (Royan, 2012).

By 2017, wastewater treatment plants in Europe are expected to amount about 37.6 billion euros. Most of them will be placed in Southern and Eastern Europe, remaining Germany as the largest national market. The capacities of municipal wastewater purification in Europe have increased in the past years. Especially many new plants were constructed in medium-sized and small towns in Eastern Europe. Already existing plants in large cities were equipped with biological wastewater treatment and additional treatment technology. The most recent new plant commissioned in a EU city with more than one million inhabitants was the facility in Bucharest in Romania in 2011 (Business Wire, 2013).

## 4.2 Case study 2: Automotive factories

Car manufacturing could be described as a sequence of activities for the production of cars. The main process activities are described in Figure 9.

- Press workshops: Where steel tiles are produced by the use of presses.
- Body workshops: Where the welding process is been carried out.
- Paint workshop: Where body car is coated and painted
- Assembly workshop: Where the assembling of parts of highest quality and precision is done.
- Quality review: Where cars are tested so as to be declared “fit for customers”.

**Figure 8: Ford Automotive Plant in Almussafes, Spain. Source:** (Ajuntament d’Almussafes, 2017)

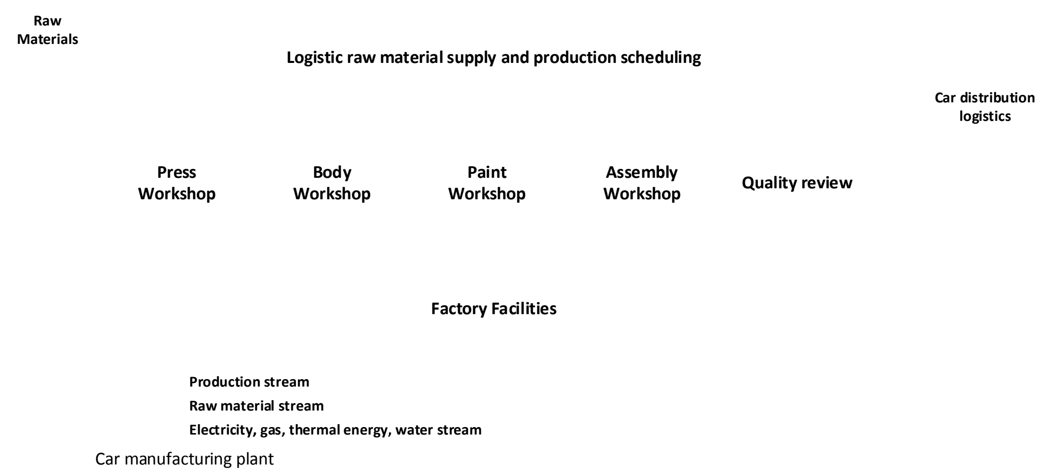



**Figure 9: Car manufacturing process. Based on source:** (Euroenergest Consortium, 2012)

During the painting process, vehicles need to be coated in some way to slow down the corrosion of the metal of which they are made. A good vehicle surface coating will also be smooth and flexible and not be easily chipped by stones. The process most commonly used today is the cathodic electrocoating process. Electrocoating has grown rapidly in popularity. The process was developed in the 1960's, and by 1970 10% of all vehicles worldwide were electrocoated. By 1990 this had increased to 90% of all vehicles, and today it is by far the most commonly used vehicle coating process (Akafuah et al., 2016; Wansbrough, 2005).

The painting process is said to carry the greatest environmental burden among all manufacturing stages of an automobile. About 80-90 % of emissions from automobile manufacturing has been associated with the painting stage. In terms of energy consumption, the painting stage consumes between 48 and 60 % of the energy required for assembling/painting an automobile (J. L. Rivera & Reyes-Carrillo, 2016).

Auto bodies are coated with paint in a five step process. The steps are as follows:

- Precleaning: to remove dirt and grease
- Phosphating: to provide a better surface for the paint and for additional corrosion protection
- Electrocoating: the actual application of the paint
- Rinsing: to remove the "cream coat" of paint that hasn't bonded to the metal surface
- Baking: to crosslink the polymeric coating

Among these processes, it has been identify the possible synergy between the phosphating and electrocoating via the application of HP – LowUP concept.

**Figure 10: Car painting. Source:** (Euroenergest Consortium, 2012)

Next points, the suitability of this case study to implement the HP – LowUP system are detailed.

### *4.2.1 Low exergy waste heat availability: Electrocoating*

A mixture of resin and binder and a paste containing the pigments are fed into a tank. The vehicle is then lowered into the tank from an overhead conveyor and an electric current applied. This car body becomes the cathode and the tank the anode in an electrocoating reaction that results in a resin polymer being very tightly and evenly bound to the metal surface of the car body.

The electrocoating tank is of steel construction with an epoxy lining to provide corrosion resistance and electrical insulation. Tanks are pH controlled, and a cathode to anode area ratio of up to 4:1 is used. Fresh paint and solvent are added to the tank as necessary. The paint is mixed and then added continually (the rate being dependent on the rate at which vehicles are electrocoated) to replace the paint solids being electrodeposited onto the vehicles. Solvent is only added as it evaporates off, which occurs particularly rapidly in slow turnover tanks.

To keep the paint particles stable and discrete, it is necessary to cool the tank. Chillers and heat exchangers are designed to hold the bath at a minimum temperature between 29ºC and 33ºC under full operating conditions. Individual types of electropaints have an optimum operating temperature to achieve a good paint stability and good deposition characteristics.

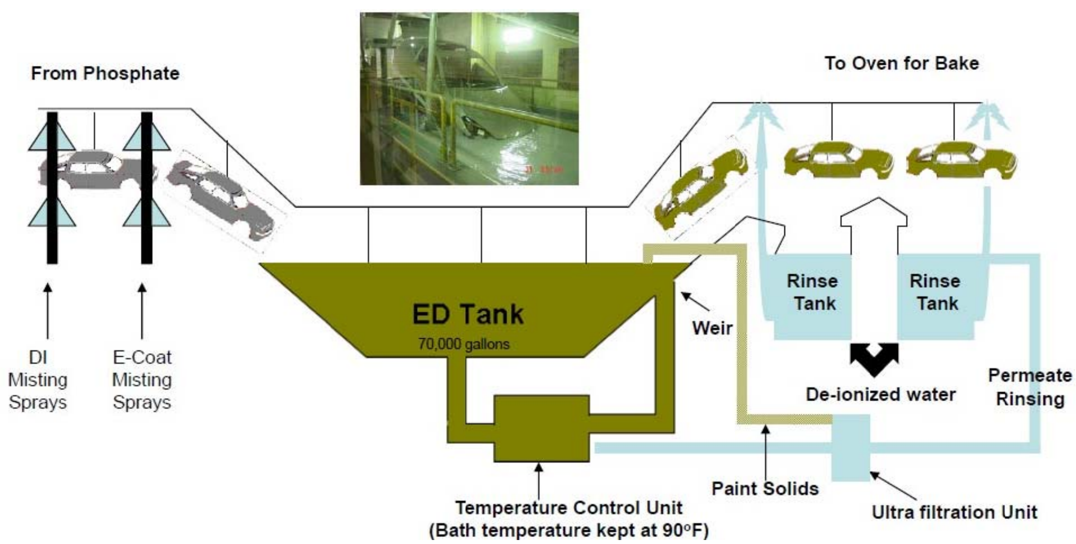



**Figure 11: Electrocoating process. Source:** (Akafuah et al., 2016)**.**

### 4.2.2 Low exergy heat demand: Phosphating

The steel that is used is layered with the outer coating being primarily zinc. This layer is sprayed with phosphoric acid ($H_3PO_4$) at 50 – 55ºC. The acid reacts with the zinc to give a mixture of zinc phosphates.

This treatment leads to a marked improvement in corrosion resistance, both directly and by helping the paint to stick. Phosphating and painting together offer 75 - 90% of the total corrosion resistance and increase the life of the vehicle by 5 - 10 years.

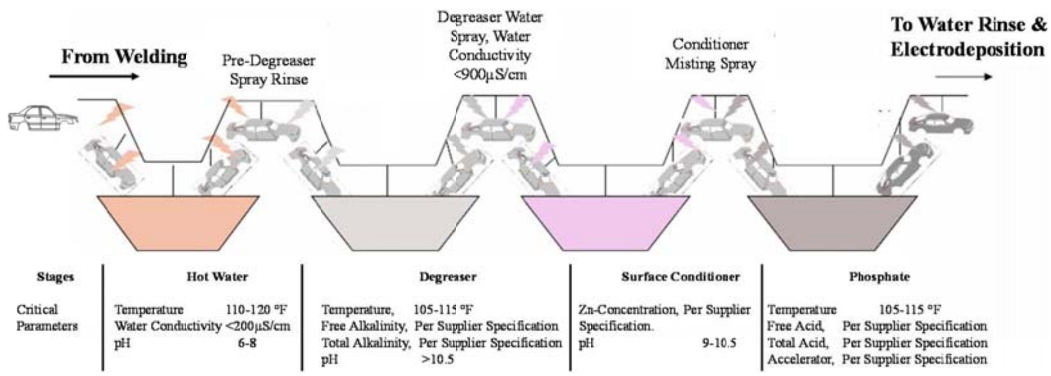



**Figure 12. Precleaning and phosphating phases. Source:** (Akafuah et al., 2016)**.**

### 4.2.3 HP-LowUP application in the automotive industry

The HP-LowUp concept will be applied between the processes of Electrocoating and Phosphating, see Figure 13. First of all, low exergy waste heat will be recovered from the electrocoating tank providing the required cooling. Then this heat will be upgraded and used in the phosphating process so as to preserve phosphoric acid at a constant temperature between 50-55ºC. Excess phosphoric acid is washed off with water and the vehicle body carried by an overhead conveyor into an electrocoat tank.

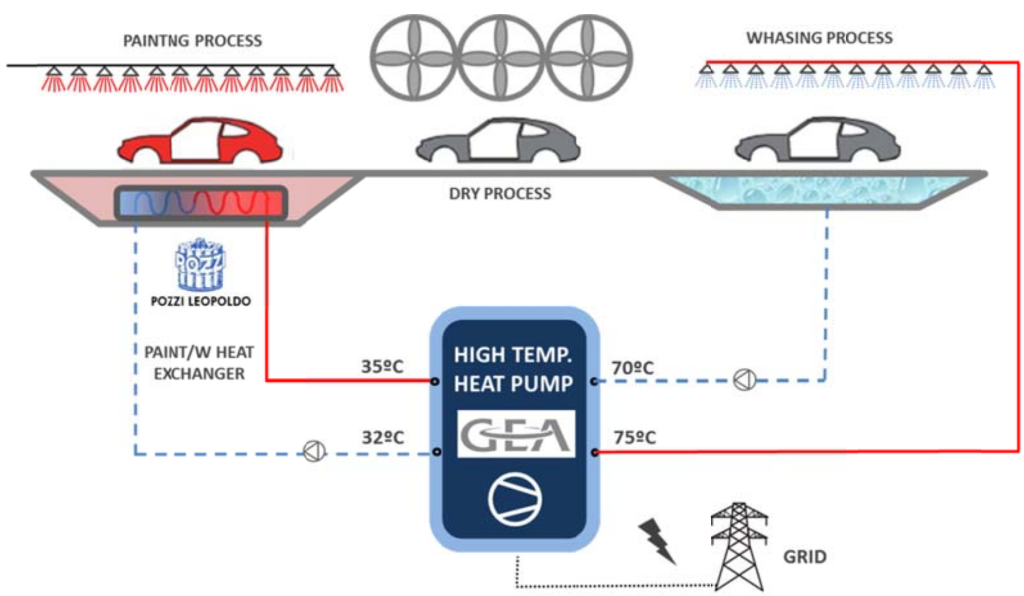



**Figure 13. HP- LowUP applied in the surface coting of car bodies.**

An estimated characterisation of the demonstration site is shown in the following table.

**Table 3 Information about case study 2. Source:** (J. L. Rivera & Reyes-Carrillo, 2016; Julio L. Rivera & Reyes-Carrillo, 2014)

| **General information** | | |
|---|---|---|
| Type of Process | Automotive body coating | |
| **Waste Heat availability** | | |
| Type of Water | Electro deposition bath | |
| Temperatures (average) | 30 | ºC |
| Flow (average) | 2.6 | $kg/m^2$ treated surface |
| Waste heat availability | 54,8 | $kJ/m^2$ treated surface |
| **Heat demand** | | |
| Type of Water | Phosphating bath | |
| Temperatures | 55 | ºC |
| Heat demand | 2940 | $kJ/m^2$ treated surface |
| **Expected Impact** | | |
| Increase in the overall efficiency | | |
| Cleaning process | 64 | % |
| Electrocoating process | 50 | % |
| Primary energy Savings | | |
| Cleaning process | 54 | % |
| Electrocoating process | 35 | % |
| CO2 Emissions reduction | | |
| Cleaning process | 69 | % |
| Electrocoating process | 57 | % |

Based on the gathered information, car body coating fulfils the requirement so as to become a case study and demonstration site for the HP-LowUP concept. Waste heat and heat demand temperatures are between the ranges of HP-LowUp concept. Moreover, it must be pointed out that the amount of the possible heat recovered in the electrocoating process, which is now of 54,8 $kJ/m^2_{\text{treated surface}}$ but could generate up to 328,8 $kJ/m^2_{\text{treated surface}}$ ue to the expected COP of the heat pump, must not be underestimated compared to the current heating demand of the phosphating process, which is around 2940 $kJ/m^2_{\text{treated Surface}}$.

### *4.2.4 Analysis of HP-LowUP replicability in the automotive industry global market:*

Based on figures provided by the European Automobile Manufacturers Association, the number of automobile assembly and production plants reached 293 in Europe in 2014. The countries with the more automotive plants are Germany (43), France (34), the United Kingdom (34), Italy (22) and Spain (15). Figure 14 shows the global current numbers for 2016-17 achieving 297 production plans only in Europe. The total energy consumption of the automotive production in Europe in 2014 was around 38.000 GWh/y. Given that 0.564 MWh of electricity is required to produce a car and the heat consumption required to produce a car represents 80% of the total energy required. So, the total heat consumption of the automotive production in Europe is around 30,400 GWh/y. As a result, the market size for HP-LowUP for the automotive industry application is estimated at 3,040 GWh/y.

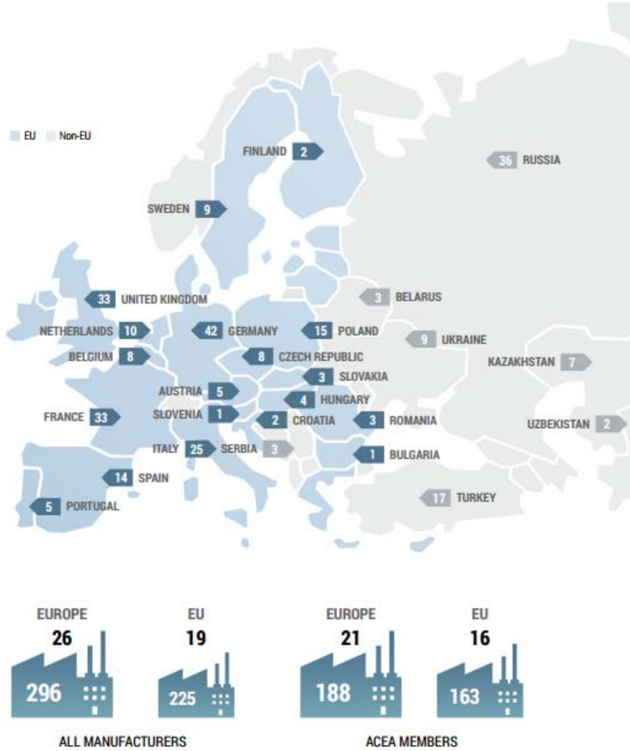



**Figure 14. Automobile assembly and engine production plants in Europe 2016-2017. Source: (ACEA, 2016).**

Manufacturers have been working continuously to improve the energy efficiency of production. As a result, energy consumption per car produced has been decreased by 14.6% over the last decade. Fluctuations in energy consumption can be explained by lower production volumes, especially during the economic crisis, as well as variable weather conditions in some years. European automobile manufactures have significantly reduced the environmental impact of vehicle production over the last decade. Long-term strategies for reducing water consumption have made it possible to reduce water use per car produced by 35.9% between 2006 and 2015.

Globally, the automotive industry has recovered from the economic crisis. Industry profits in 2012 (EUR 54 billion) were much higher than in 2007 (EUR 41 billion), the last precrisis year, and the prognosis for future growth is even better. By 2020, global profits could increase by another EUR 25 billion, to EUR 79 billion. The new profits will come mainly from growth in emerging markets and, to a lesser extent, the US. Europe, Japan, and South Korea will be stagnant in terms of profit growth (Mohr, D; Muller, N; Krieg, A; Gao, P; Kaas, H W; Krieger, A; Hensley, 2013).

At the end of 2013, the European Parliament and the Council of the European Union reached an agreement regarding two regulatory proposals that will implement mandatory 2020 $CO_2$ emission targets for new passenger cars and light-commercial vehicles in the European Union. The passenger car standards are 95 g/km of $CO_2$, phasing in for 95% of vehicles in 2020 with 100% compliance in 2021. The light-commercial vehicle standards are 147 g/km of $CO_2$ for 2020. Since a quarter of Europe’s GHG emissions come from the transport sector, reaching these targets will have a powerful impact and create a ripple effect, since many countries pattern their regulations on the European standards. $CO_2$ standards for new vehicles in the post-2020 timeline are currently under preparation by the European Commission (The International Council on Clean Transportation, 2017).

## 4.3 Other cases: Pulp and Paper mills.

HP-LowUP concept application is not limited to the applications described in sections 4.1 and 4.2, other processes have been already identified as potential applications.

The pulp and paper (P&P) industry is one of the heaviest users of water within the industrial economy, requiring 54 $m^3$ on average of water per metric ton of finished product. With water used in nearly every step of the manufacturing processes, P&P mills produce large volumes of wastewater (at different temperatures) and residual sludge waste, presenting a number of issues in relation to wastewater treatment, discharge, and sludge disposal.

The main steps in pulp and paper manufacturing are: Raw material preparation and handling, Pulp manufacturing, Pulp Washing and Screening, Chemical recovery, Bleaching, Stock Preparation, and Papermaking. Approximately 85% of the water used in the P&P industry is used as process water, resulting in relatively large quantities of contaminated water and necessitating the use of onsite wastewater treatment solutions.

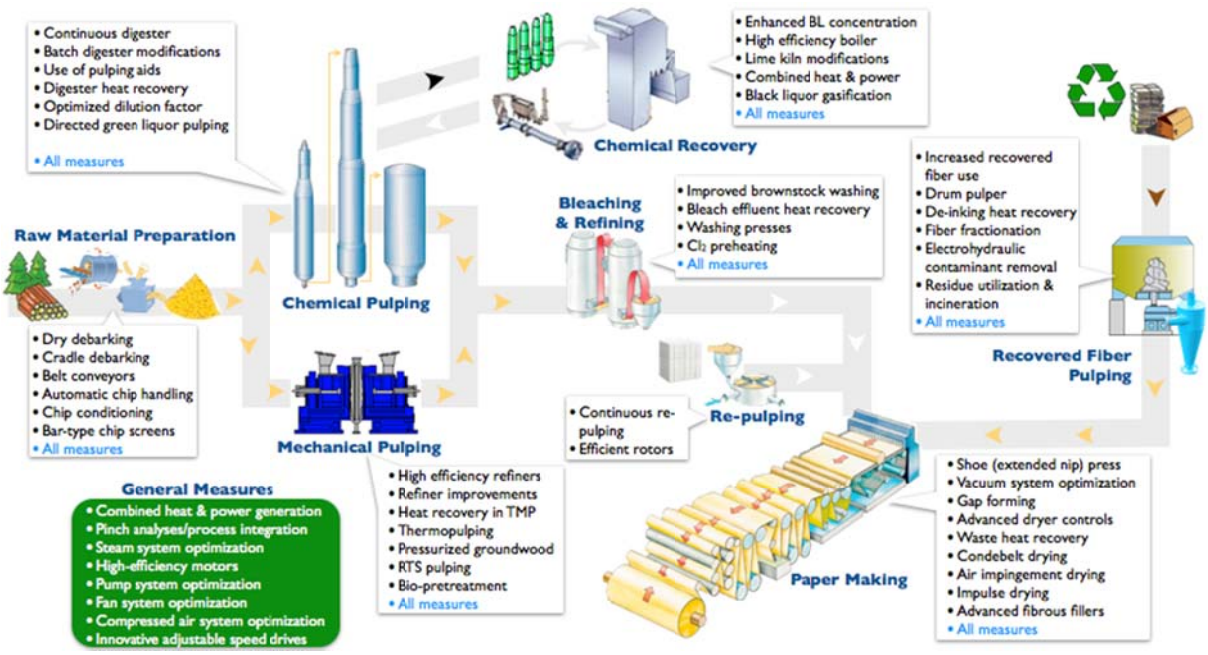



**Figure 15: HP- Paper making process (Borzacconi & Noel, 2013).**

For many years, the majority of pulp and paper mills have used the process of clarification - a common primary treatment method - to reduce and remove total suspended solids (TSS) and other inevitable particulate matter such as bark, dirt and wood fibers generated from the paper-making process. Treatment options include secondary biological treatment processes for removing biodegradable organic matter and decreasing the effluent toxicity. Composed mainly of boiler and furnace ash, scrubber sludge, lime mud, wood processing residuals, and various effluent solids, sludge is the largest volume waste stream generated by the industry, making sludge handling a very important issue.

Manufacturing of pulp starts with raw material preparation. Cellulosic pulp is manufactured from the raw materials, using chemical and mechanical means. The main processes are Stone Groundwood Pulping (SGW), Pressure Groundwood Pulping (PGW), Thermo-Mechanical Pulping (TMP), or Chemi-Thermo-Mechanical Pulping (CTMP). Thermomechanical pulps, which are used for making products such as newsprint, are manufactured from raw materials by the application of heat, in addition to mechanical operations. The process involves high-temperature steaming before refining; this softens the interfiber lignin and causes partial removal of the outer layers of the fibers, thereby baring cellulosic surfaces for interfiber bonding.

After pulp production, pulp is processed in wide variety of ways to remove impurities, and recycles any residual cooking liquor via the pulp washing process. Some pulp processing steps that remove pulp impurities are screening, de-fibering, and de-knotting. Residual spent cooking liquor from chemical pulping is washed from the pulp using pulp washers, called brown stock washers for Kraft and red stock washers for sulfite.

Different kinds of wastewaters are available at different steps and stages, with different concentrations and kinds of pollutants, with residual temperatures depending on the precedence transformation process. The P&P industry is characterized by high technological level and by high degree of self-sustainability from the energetic point of view, through the fully utilization of wood treatment sub-products for steam based co-generative cycles.

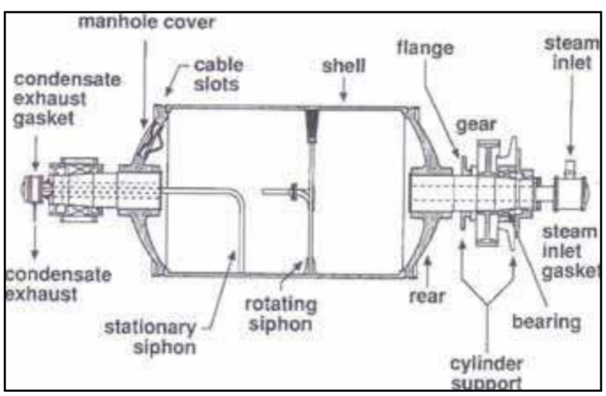
Nevertheless wastewaters with temperatures below 30ºC are not considered relevant for heat recovering processes, because of their low level of exergy, even if with big amount of energy due to the elevated number of $m^3$ of water, which would require investment with large payback.

### 4.3.1 Low exergy waste heat availability: Activated Sludge's from the pulp making processes.

The HP-LowUp concept pretends to benefit the P&P industry recovering the un-used low enthalpy waste heat from polluted wastewaters, increasing the energy efficiency of the entire production process, and boosting it for other energetic purposes. The effluent has here temperatures around the 35 ºC, and a solid charge higher than in the case that the urban waste water treatment plants.

### 4.3.2 Low exergy heat demand: pre-heating of replacement water in steam process generation.

Due to the elevated consumption of steam, it can be proposed to make a pre-heating of the demineralized water used for steam generation, reducing the contribution of fossil fuel from steam boilers. Steam is extensively used across all the Paper Plants, as multifunctional way to supply heating to process, for example, to the drying of the paper. Not all the vapour is recovered via condensates, so continuous replacement should be performed.



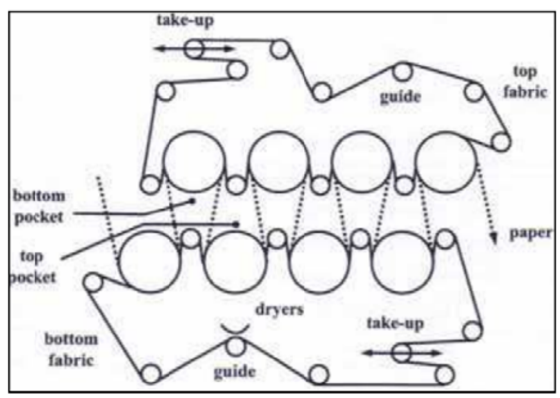




**Figure 16: Sectional view of a dryer cylinder and Conventional Two tier dryer configuration.[21.]**

The rate of vapour consumed in the paper making varies depending of the type of paper manufactured, varying between 1.5 and 4 kg vapour/kg Paper [21.] (see next figure).

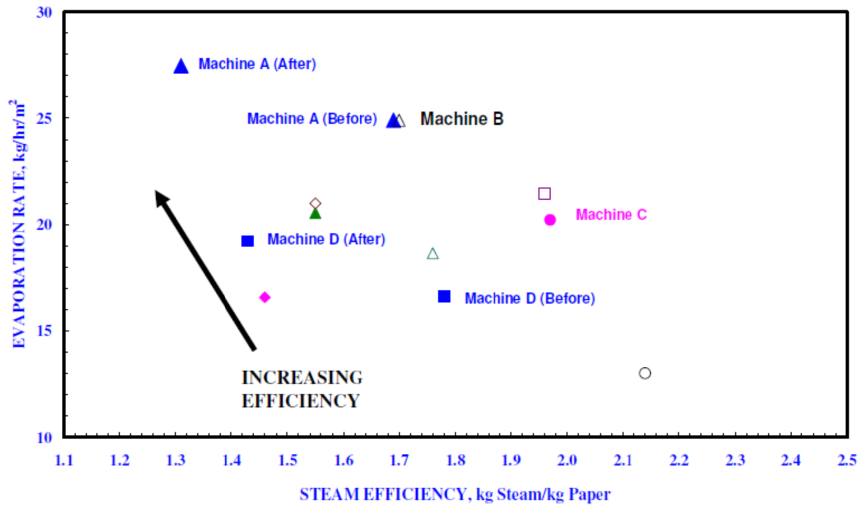



**Figure 17: Overall dry-end efficiency for paper machine making corrugating medium.[21.]**

Actually, and even to the presence of high efficiency systems such Natural gas based CHP (Combined Heat and Power), the use of boiler in the heating (pre-heating) of water for vapour preparation is extended. The HP-LowUP technology can complement specially in the stage of pre-heating the replacement water, that can comes from the distribution network at temperatures around 15 ºC (medium) and is able to heated up to the 75-80ºC that our system can supply.

### *4.3.3 Analysis of HP-LowUP application in the paper mills plants.*

The Total production of Paper pulp can be estimated around 40 MTonn/year, following the statistics of the Confederation of European Paper industry [20.]

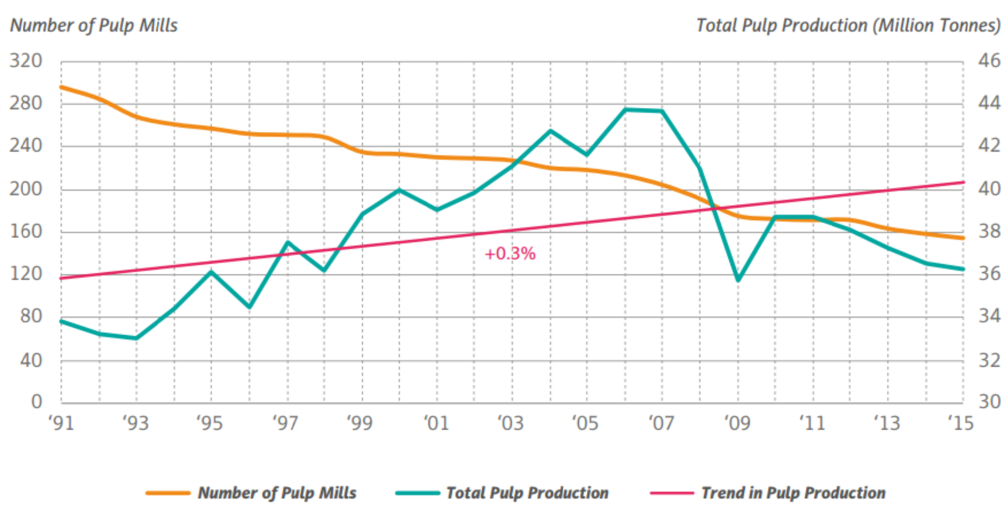



**Figure 18: Number of CEPI Pulp Mills and Total Pulp Production [20.]**

Just for a rough estimation, if we consider that to dry all this pulp production a medium rate of 2 kg vapour/kg Paper is used, and the 3% of the vapour is not recovered, and should be replaced, the energy that can be supplied by the HP-LowUP rises up the figure of 150 GWh/year, whose cost with conventional boiler are close to 5 M€/year.

Next figure informs about the countries where the production is concentrated, just with the intentions of considering where the potential opportunities for the HP-LowUP can be located; it is interesting to appreciate that 3/4 of the production is focused in Northern and Atlantic countries, where the features of HP-LowUP can be even more interesting.

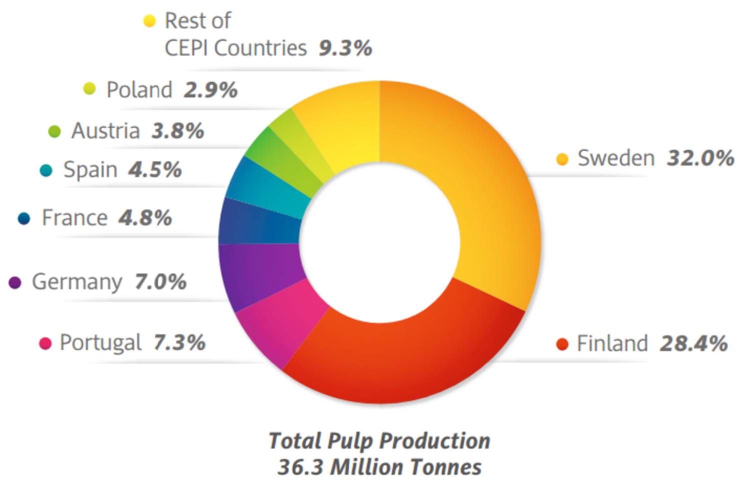



**Figure 19: CEPI Total Pulp1 Production by Country in 2015 [20.]**

# 5 Development and demonstration methodology

In order to test and demonstrate the expected efficiency of the HP-LowUP, several tasks will be done in the laboratories of the consortium partners and the final tests will be made at the thermal laboratory facilities of ACCIONA, located in Seville, Spain. The development and demonstration methodology will consist in the analysis of the system's efficiencies under different operation conditions, in terms of energy availability and energy demands, as well as under different operation strategies, taking into account multiple optimization criteria and the requirements from the industrial processes.

This development and demonstration process consists of seven stages, as depicted in Figure 20. Eaxh step is explained later on.

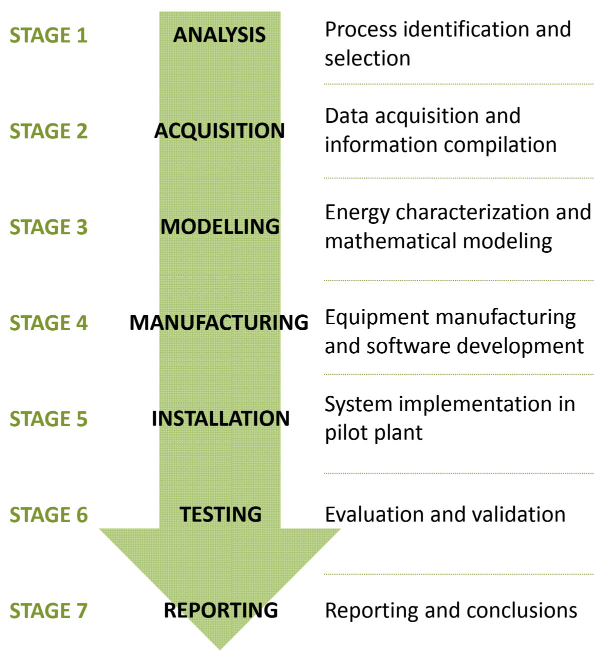



**Figure 20: Diagram of the development and demonstration process**

### 1. Process identification and selection:

The most promising processes of automotive factories and water treatment plants are being analyzed in order to identify the availability of waste heat resources. One of the results of this stage is this document, where the characteristics of the processes haven identified to assure the right applicability of the HP-LowUP system.

During the analysis, aspects such as power, capacity, water temperatures, suspended contamination, type of process, discontinuity and duration of operation are considered in order to identify the best candidate processes for waste heat recovery through the HP-LowUP system.

### 2. Data acquisitions and information compilation:

The demonstration sites are defined and a preliminary monitoring is being implemented in order to acquire data related to the processes and their operations' characteristics. The monitoring allows the data capture for further analysis to determine demand and waste energy profiles. During the monitoring campaign, the data is being centralized into a database in order to be accessible and processed by the consortium.

### 3. Energy characterization and mathematical modeling:

During this stage, the acquired data are being analyzed and processed in order to extract information related to waste heat availability (in terms of time and working conditions), patterns of energy demand, equipment's coefficients of performance and boundary conditions. The data is being used to develop the mathematical models of the energy resources and demands that are being used during the energy prediction tasks, as well as to design the system layouts. Figure 21 shows the initial theoretical model of the HP-LowUP system.

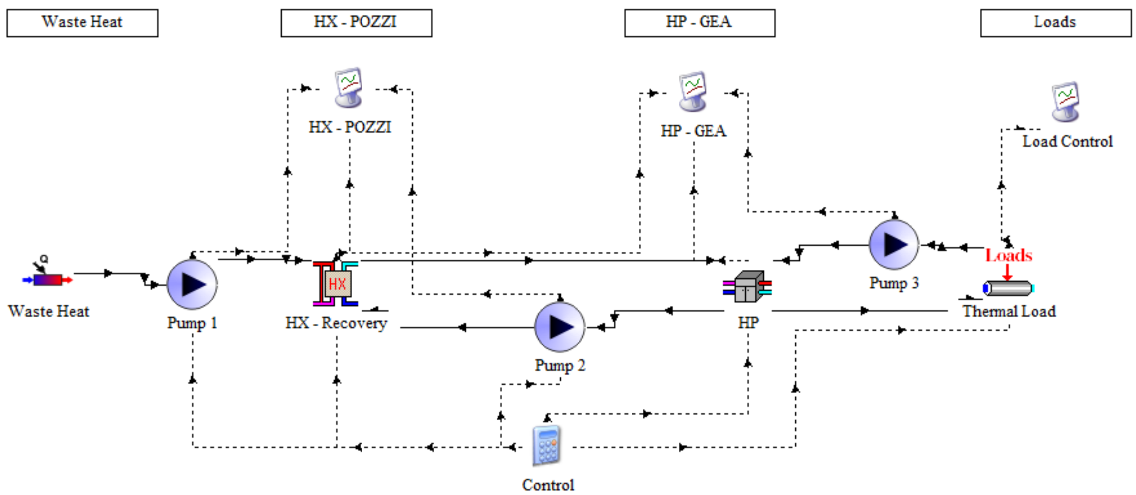



**Figure 21: Initial HP-LowUP TRNSYS model.**

### 4. Equipment manufacturing and software development:

Stage 4, which begins early in the project and is executed in parallel to the previous activities, includes the study, characterization and development of the heat exchangers and heat pump technologies. The development of the each system is done by each manufacturer in house. Once the systems were finished and validated internally they will be sent to the thermal laboratory facilities of ACCIONA.

Furthermore, the algorithms for the optimal control and supervision are being developed, taking into account the acquired information from the demonstration sites, as well as the operation efficiencies of the equipment.

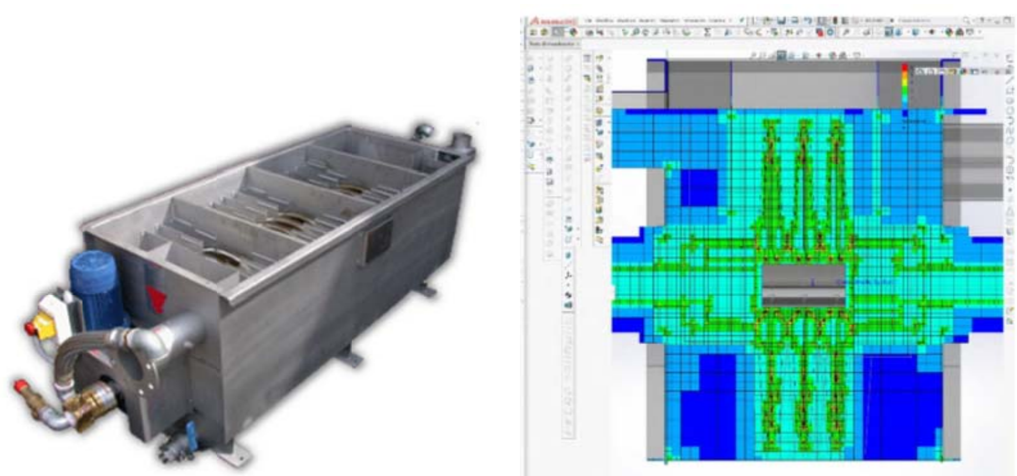


**Figure 22: CFD simulations carried out during the heat exchanger design.**

**Figure 23: Heat pump initial design.**

### 5. System implementation in pilot plant:

The developed heat pump and software modules are shipped and installed into the thermal laboratory of ACCIONA, located in Seville, where the validation of the technology will take place. The developed heat exchanger is sent to the demonstration sites where it will be operated. This stage includes the physical installation of the equipment with the hydraulic and electrical circuits, their instrumentation and the programming of the control system (SCADA system and communication with the PLCs), as well as the integration of the control and supervisory algorithms.

Figure 24 presents the concept diagram of the demonstration process, which consists in the monitoring of the real operation conditions of the heat exchanger in the demonstration sites, their storage, and their replicability in the controlled environment of the ACCIONA thermal laboratory at Seville for the demonstration of the HP-LowUP solution.

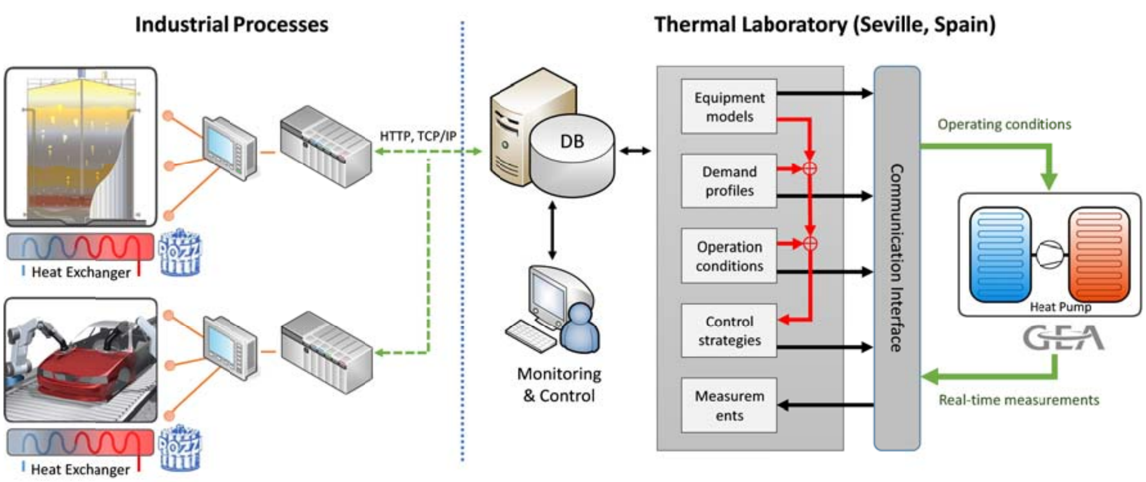



**Figure 24. Concept diagram of the demonstration process.**

### 6. Evaluation and validation:

During this stage, the testing of HP-LowUP takes place, implementing different operation conditions, based on the characterized profiles of energy sources and demands. The tests are monitored and studied afterwards. KPI are used so as to monitor and evaluate the obtained results, Table 4 shows the preliminary KPI list defined by the consortium.

Based on the obtained results, possible tuning actions for the mathematical models and algorithms is applied in order to maximize their accuracy. Furthermore, the control algorithm is being evaluated by testing different operation strategies to determine the energy consumption and operation costs for different optimization criteria. Similarly, the algorithm of energy supervision and predictive maintenance is being tested, applying controllable fault conditions and indicators.

**Table 4: Initial KPI defined for the HP-LowUP evaluation.**

| System | Symbol | Unit | Description |
|---|---|---|---|
| Heat pump (HP) | $PE_{HT}$ | kW | Instantaneous electric power consumed by the HT |
| | $EE_{HT}$ | kWh | Total electric energy consumed by the HT |
| | $PQd_{HP}$ | kW | Instantaneous thermal power delivered by the HP |
| | $EQd_{HP}$ | kWh | Total thermal energy delivered by the HP |
| | COP | - | Instantaneous coefficient of performance of the HP |
| | sCOP | - | Seasonal coefficient of performance of the HP |
| | $AT_{RS}$ | K | Temperature lift between the wastewater stream and the stream where the thermal energy is delivered by the HP |
| Heat Exchanger (HX) | $PQ_{HXW}$ | kW | Instantaneous thermal power availability from the wastewater source |
| | $EQ_{HXW}$ | KWh | Total thermal energy availability from the wastewater source |
| | $PQ_{HXR}$ | kW | Instantaneous thermal power recovered by the HX |
| | $EQ_{HXR}$ | kWh | Total thermal energy power recovered by the HX |
| | $\eta_{HR}$ | - | Heat exchanger efficiency |
| | $\varepsilon_{HR}$ | - | Heat exchanger effectiveness |
| Integrated System | $P_{aux}$ | kW | Electric power consumed by auxiliary equip (pumps, valves, control, etc.) |
| | $E_{aux}$ | kWh | Energy consumed by auxiliary equipment (pumps, valves, control, etc.) |
| Environmental impact | $GHG_s$ | $kgCO_2eq$ | GHG emissions saving compared with a conventional system |
| | PES | kWh | Primary Energy Savings |
| Economic evaluation | CAPEX | €/kW | Capital expenditures per kW installed |
| | OPEX | €/KWh | Operating expenses per kWh produced |

Figure 25 shows an image of the adiabatic cooling tower and the wet cooling tower available in the Acciona Thermal Lab for thermal loads emulation.

Figure 25. ACCIONA facilities. Thermal Lab

## 7. Reporting and conclusions:

Following the development made in the previous stages, according to the results obtained during the manufacturing, installation, commissioning and operation, sensible conclusion about the readiness of the prototype systems is being carried out at the components and the process to prove the industrial potential and its integration within the energy system.

Important conclusions are reported in this stage, not only by gathering all the conclusions from the previous stage (data analysis), but also from the recovery and list of the learn lessons extracted from either the technical point of view (performance, best control strategies, optimization opportunities), but also from other parallel issues (constructive, standards, legal and permitting, behavioral)

## Conclusion

This report has presented the HP-LowUP concept, which is focused on the low valued energy recovery in the industrial sector. The HP-LowUP concept will enable to recover low temperature heat, between 20ºC and 45ºC, to upgrade it to a higher temperature, between 80 and 55ºC, to be reused finally it in the same industrial process.

Moreover, the anaerobic digestion (wastewater treatment plans), and the body car coating (automotive industry), have already been identified as suitable "case studies" for the demonstration and validation of HP-LowUP technology, the third and last system arising from the Project. Such demonstrations will occur in the scope of the WP4. . Those processes has been analyzed and assessed to verify they can be used to demonstrate the project objectives and they can be used to replicate the technology developed. Another process from the paper industry is identified as a potential low valued energy recovery process, as well as others cases related to the food industry. Finally, the HP-LowUP development and demonstration methodology has been presented and some of the current developments, regarding WP3, have been pointed out.

From now on, WP3 partners will be focused mostly on finishing the case studies assessment and on the selection of the specific case studies to be demonstrated over the WP4. Meanwhile the rest of the tasks regarding WP3, development of the heat exchanger, heat pump and the supervision system, will continue.

This deliverable is the main result of the Task 3.1, however some results of this task have not been included in this deliverable as they are confidential; many of them are related to the preparation of the demonstration in cooperation with "external industrial collaborators". The description of the layouts, technical specifications and features for the components and global system to accomplish the HP-LowUP systems to be implemented over the demo sites will be included in the following WP3 deliverables.

## Bibliography and References


[1.] ACEA. (2016). Automobile Industry Pocket Guide 2016-17. Retrieved from http://www.acea.be/uploads/publications/ACEA_Pocket_Guide_2016_2017.pdf

[2.] Ajuntament d'Almussafes. (2017). Ajuntament d'Almussafes. Retrieved from http://www.almussafes.es/es/page/urbanismo-servicios

[3.] Akafuah, N., Poozesh, S., Salaimeh, A., Patrick, G., Lawler, K., & Saito, K. (2016). Evolution of the automotive body coating process—A review. *Coatings*, *6*(24), 1–22. http://doi.org/10.3390/coatings6020024

[4.] Bachmann, N. (2015). Sustainable biogas production in municipal wastewater treatment plants, 20. Retrieved from http://task37.ieabioenergy.com/files/daten-redaktion/download/Technical Brochures/Wastewater_biogas_grey_web-1.pdf

[5.] Borzacconi, L., & Noel, M. (2013). Pulp and Paper Making Wastes , Treatment and Environmental Effects. Colonia del Sacramento.

[6.] Business Wire. (2013). Research and Markets: Sewage Plants in Europe. Retrieved from http://www.businesswire.com/news/home/20131105006213/en/Research-Markets-Sewage-Plants-Europe-Larger-Capacities

[7.] Canal de Isabel II. (2008). EDAR Arroyo Culebro Cuenca Baja. Retrieved from www.canalciclointegraldelagua.es/.../cuenca.../arroyo-culebro-cuenca-baja/pdf.pdf

[8.] EUBIA. (2016). Anaerobic Digestion. Retrieved from http://www.eubia.org/cms/wiki-biomass/anaerobic-digestion/

[9.] Euroenergest Consortium. (2012). FP7 EUROENERGEST - INCREASE OF AUTOMOTIVE CAR INDUSTRY COMPETITIVENESS THROUGH AN INTEGRAL AND ARTIFICIAL INTELLIGENCE DRIVEN ENERGY MANAGEMENT SYSTEM - Public Report on WP1.

[10.] Lemmens, S. (2015). Waste heat recovery : potential , policy challenges and technology choices. In Conference: 38th IAEE International Conference. Antalya, Turkey.

[11.] Metcalf & Eddy, I., Tchobanoglous, G., Burton, F., & Stensel, H. D. (2002). *Wastewater Engineering: Treatment and Reuse*. McGraw-Hill Education. Retrieved from https://books.google.es/books?id=-eoeAQAAIAAJ

[12.] Mohr, D; Muller, N; Krieg, A; Gao, P; Kaas, H W; Krieger, A; Hensley, R. (2013). The road to 2020 and beyond: What's driving the global automotive industry? *McKinsey & Company*, 24. http://doi.org/10.1007/978-3-319-02868-2_3

[13.] Rivera, J. L., & Reyes-Carrillo, T. (2014). A framework for environmental and energy analysis of the automobile painting process. *Procedia CIRP*, *15*, 171–175. http://doi.org/10.1016/j.procir.2014.06.022

[14.] Rivera, J. L., & Reyes-Carrillo, T. (2016). A life cycle assessment framework for the evaluation of automobile paint shops. *Journal of Cleaner Production*, *115*, 75–87. http://doi.org/10.1016/j.jclepro.2015.12.027

[15.] Royan, F. (2012). Sustainable water treatment technologies in the 2020 - Global water market. Retrieved from http://www.forburyinvest.com/fileuploads/Frost & Sullivan.pdf

[16.] The International Council on Clean Transportation. (2017). EU vehicle targets. Retrieved from http://www.theicct.org/spotlight/eu-vehicle-targets

[17.] U.S. Department of Energy. (2008). *Waste Heat Recovery: Technology and Opportunities in U.S. Industry*.

[18.] UrbanWater Consortium. (2013). *UrbanWater : Intelligent Urban Water Management System .* Retrieved from http://urbanwater-ict.eu/wp-content/uploads/2014/08/URBANWATER-D1.1-The-European-Water-Market-Analysis.pdf

[19.] Wansbrough, H. (2005). The surface coating of car bodies. *New Zealand Institute of Chemistry*, 1–13. Retrieved from nzic.org.nz/ChemProcesses/polymers/10F.pdf

[20.] Key Statistics European pulp & paper industry (2015) *CEPI Confederation of European Paper Industries.*

[21.] Ajit K Ghosh "*Fundamentals of Paper Drying – Theory and Application from Industrial Perspective Principal*", AKG Process Consulting, 33 McFarlane Court, Highett, Australia