MODULE 1

CHAPTER 1 DESCRIPTION OF WASTE HEAT AND COOLING

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the European Union’s Horizon 2020 research and innovation
programme under grant agreement No 847097

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ABBREVIATIONS

BF-BOF: Blast Furnace and Basic Oxygen Furnace

EAF: Electric Arc Furnace

ESCO: Energy Service Company

EU: European Union

LNG: Liquefied Natural Gas

ORC: Organic Rankine Cycle

RES: Renewable Energy Sources

WH/C, WH/WC: Waste Heat/Cold

WHR: Waste Heat Recovery

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SHORT SUMMARY

In this module, it will be given a detail description of how to investigate the waste heat & cold energy consumption and the potentials regarding the technology and how to exploit it externally for an industrial plant. The main inputs at this document come from the study conducted within SOWHAT project in WP1 and WP2 and some deliverables linked:

- D1.2 First release of SO WHAT Industrial Sectors WH/C recovery potential.
- D1.5 Strategies and protocols for input data collection.
- D1.6 Report on H/C recovery/storage technologies and renewable technologies).
- D2.1 Report on end-users' current status, practises and needs in waste H/C recovery and RES integration.

Three pillars constitute the basis for this training module: industrial energy auditing, WH/C exploitation inside and outside the industrial site and the related technologies to achieve such objective, which is reflected in the following structure of the handbook. This module will address the topics related to general aspects of the above-mentioned pillars and it will provide technical inputs to the trainee and a solid basis for the prosecution of the training activities.

The handbook structure is here reported:

- Chapter 1: Description of the waste H/C: how it is generated and where it can be seen most in the industrial plants.
- Chapter 2: Analysis of WH/C technologies.
- Chapter 3: Insights into the data needed to be collected to run the simulations and the related formats.
- Chapter 4: Inputs related to the mapping, the tool's needs to map local RES and municipality or an industrial plant feature.
- Chapter 5: High-level information and details linked to the simulation environment, including possible checks and evaluation of the consistency of data.
- Chapter 6: The cause-effect relation between input data and outputs will be introduced in terms of qualitative and quantitative information.

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1 Introduction

Thermal and mechanical processes always produce waste heat (WH) to the point that between 20 and 50% of the industry energy consumption finally ends as WH, of which a significant part between 18 and 30% could be used, according to estimations.

In the European Union, domestic hot water, space heating and other ways of process heating account for more than 50% of the energy use. But centring our scope in industry and according to the European Commission data [1], the 70% of the energy used in the European industry is used for space and industrial process heating (193.6 Mtoe). Taking into account this figures, the waste heat may represent an important source of energy as long as its recovery and use become technically and economically feasible, which may suppose between 7 and 30 Mtoe saved annually with its respective money and emission savings.

Starting to talk about the technical point of view of waste heat recovery (WHR), three main components are required to accomplish it: 1) a source of waste heat, 2) a recovery technology, and 3) an end use for the recovered energy. This concept, represented in Figure 1, is a key point to understand the conditions needed for a good implementation of a WHR strategy so that it will be totally unfeasible in case one of the three parts is not assured.

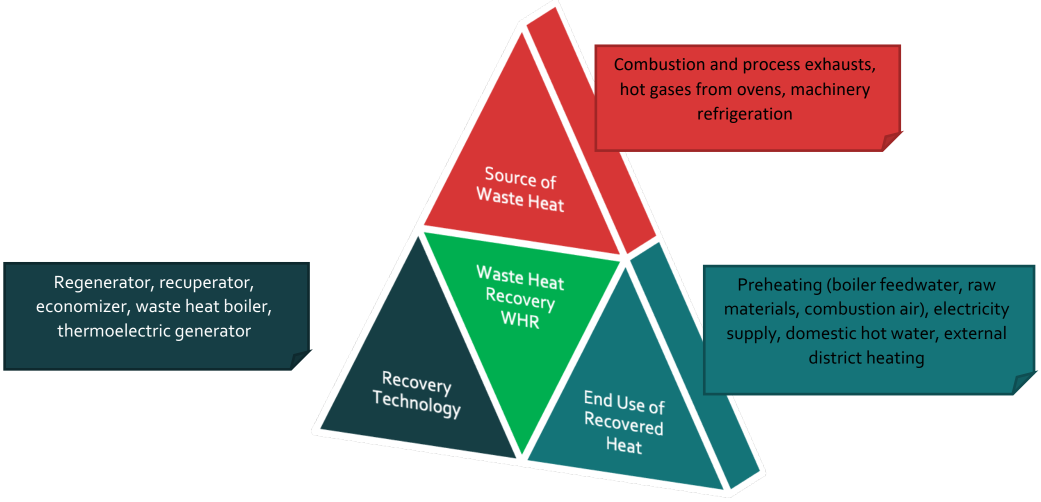

Figure 1 Essential components for Waste Heat Recovery (WHR) [2]

The sources of WH differ among themselves in the physical state, the temperature ranges, their type of occurrence and of course the power thermal available. WH is generated along the industrial processes as a by-product in different forms such as combustion gases, heated water or heated products. As depicted in Figure 2, conversion losses and end-user losses represent possible sources of waste heat, while distribution losses are not usually considered as sources of WH but non-usable system inefficiencies.

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Energy cycle and waste heat sources

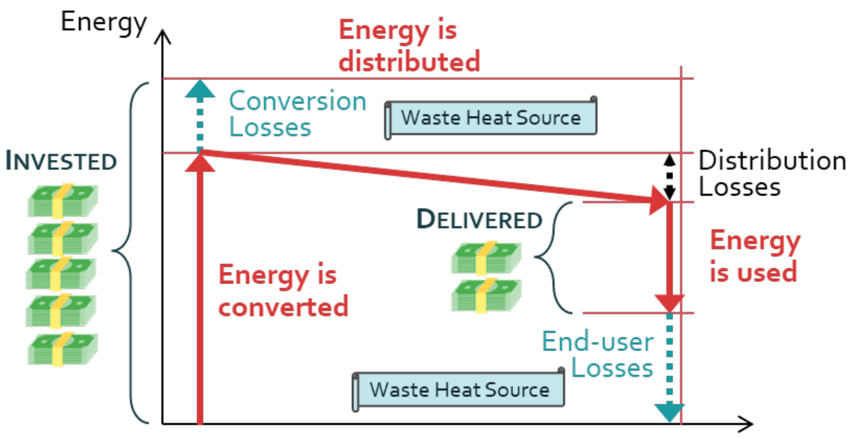

Figure 2 Industrial processes energy cycle [2]

Most waste heat recovery devices transfer heat from a higher temperature effluent stream to another lower temperature inlet stream. WH can also be used by passing hot gases or steam through a turbine to generate electricity. Therefore, as a general rule, it can be considered that the "usefulness" of a WH will be determined by its temperature, so that the higher its temperature, the higher its quality. The typical temperature ranges of processes commonly present in industry are described in Figure 3.

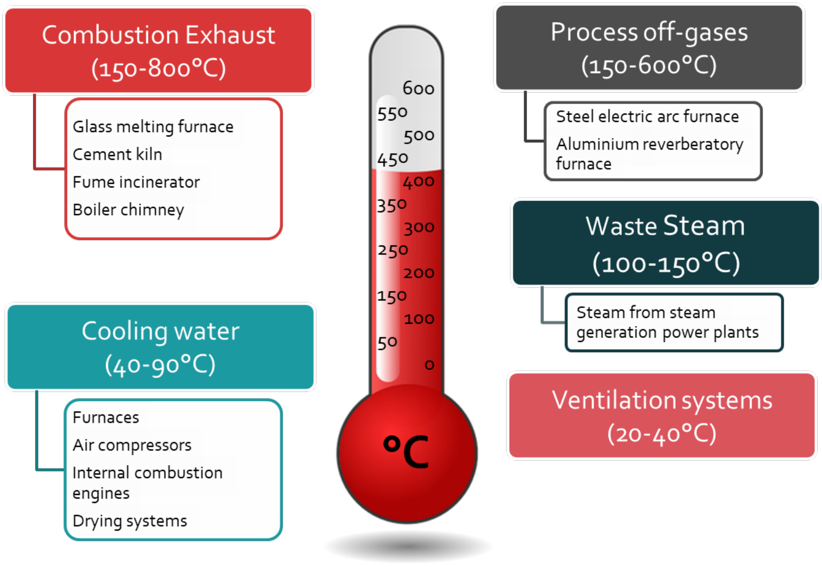

Figure 3 Industrial waste heat sources [2]

In sections below, the main sources of waste heat and the possible end use of the recovered heat will be described.

2 Sources of waste heat

This section is focused in the description of the main energy consuming industrial processes with the highest heat recovery potential.

Non-ferrous metals

In this sector, some of the available waste heat is in the form of high temperature fumes but the most part comes from lower temperature heat sources (less than 200°C). These heat sources can most typically used for space heating or ORC machines to generate power.

Aluminium

The most common process to produce aluminium is the known as Hall-Héroult process (Figure 4). This process is performed at high temperature; however the amount of waste heat is limited due to the relatively large distances between sources and sinks. The fact that most sources are at low temperature of 300°C or lower joined to the presence of high dust loading of the streams so that the use of heat exchangers is difficult, make heat recovery to be focused in space heating and preheating of raw materials both in primary operations and in auxiliary processes.

Figure 4: Electrolytic Hall-Héroult smelting process. Source: Shutterstock

Zinc and Cadmium ore roasting

Zinc and Cadmium ores participate in an exothermic process carried out at 900°C approximately using a fluidised bed in oxygen enriched air. Waste heat is recovered through cooling systems of the machines, and it can be used to produce steam for power generation.

Sintering and roasting processes of other ores

The processes of sintering and roasting are usually high temperature and there exist opportunities for recovering waste from flue gases for pre-heating air of produce steam.

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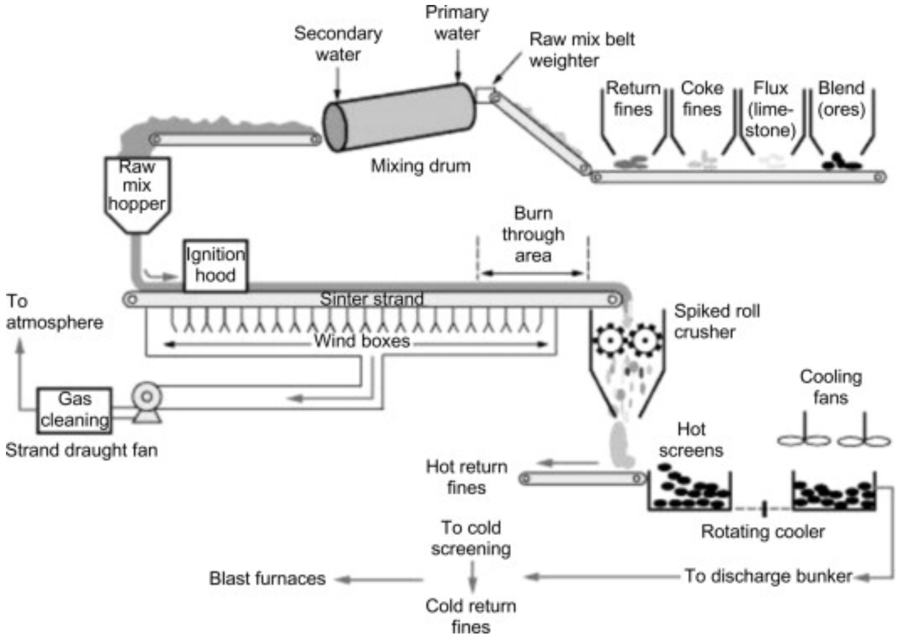

Figure 5: Schematic of a sintering plant [4]

Non-metallic minerals

The production of non-metallic minerals such as cement, lime, gypsum and ceramics is energy intensive and processes require high temperatures.

Cement

Cement is produced by a process of calcining and sintering a mix of different metallic and mineral components in a rotary kiln at temperatures of around 1.450°C to form clinker. Clinker usually constitutes at least 90% of ordinary Portland cement. The exhaust gas from the kiln is usually used to pre-heat the cement raw materials before entering the kiln.

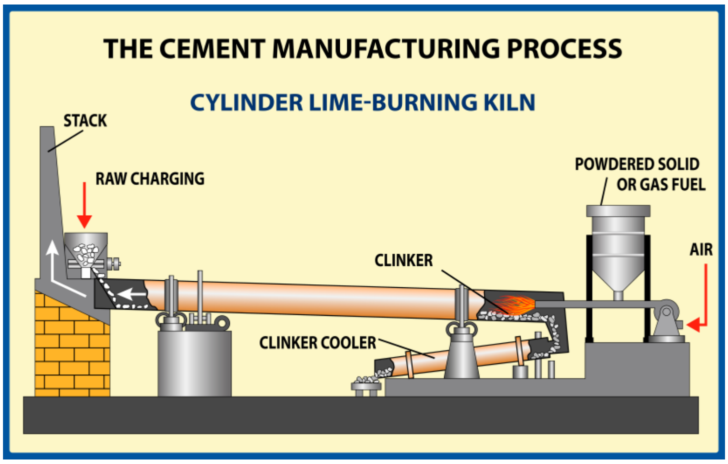

Figure 6 Energy output flows of a modern dry type clinker kiln. Source: Shutterstock

A modern kiln will use approximately 3.300 MJ per tonne of product using 55% of the energy to drive the process of clinker formation. A typical modern dry clinker cement kiln are shown in Figure 6.

The gases coming from coolers or preheaters have a typical temperature between 250-380°C, representing 11% of the energy involved in the process. These hot gases can be used to generate

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electricity producing steam or using a Rankine Cycle. Even in a modern plant, 0.3 GJ of energy per tonne of clinker is calculated to be available in the exhaust streams.

Lime

Lime is produced by heating crushed limestone to approximately 900°C in vertical or rotary kilns in a process known as calcination (Figure 7).

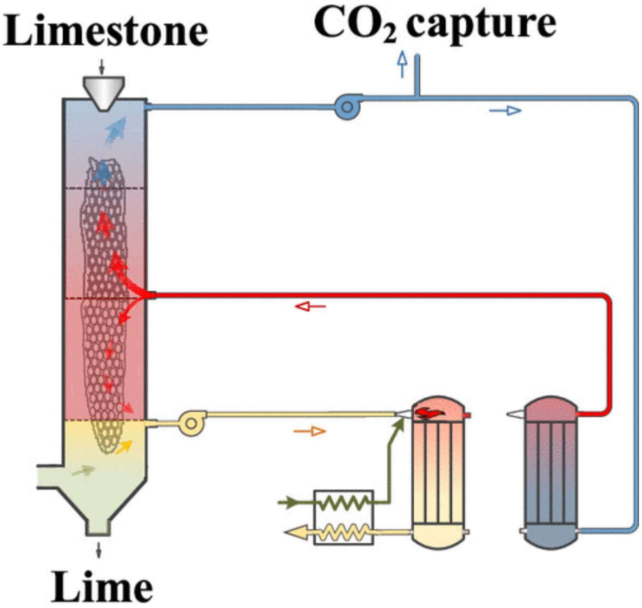

Figure 7: Vertical kiln for calcination process [6]

Waste gases from the calcination can be used for pre-heating the limestone being fed into the process. Cooling air from cooling the lime may be used as warmed combustion air in the kiln recuperating heat coming directly from the product.

Glass

Glass is produced by melting a mixture of sand, minerals and recycle glass in a furnace at a temperature of over 1500°C (Figure 8). Using economizers to preheat combustion air is a common practice due to the fact that over half the energy from glass furnace exhaust gases can be recovered. There are also examples of energy recovery from glass manufacturers using ORC machines.

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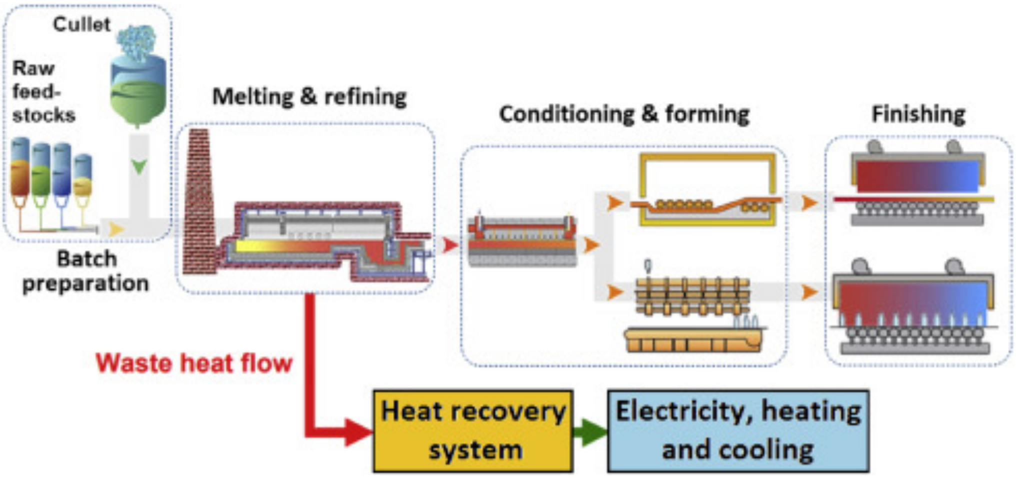

Figure 8: Glass production processes [7]

Chemical and petrochemical

Crude oil is processed by first desalting before being distilled into the fractions required. Typically the oil is heated using heat exchanged from hot distilled fractions before being heated to 400°C by a furnace and fed into a distillation column. After distillation, the lighter fractions are reformed and hydrotreated to produce gasoline and diesel, while heavy fractions are cracked. A diagram of the process is shown in Figure 9.

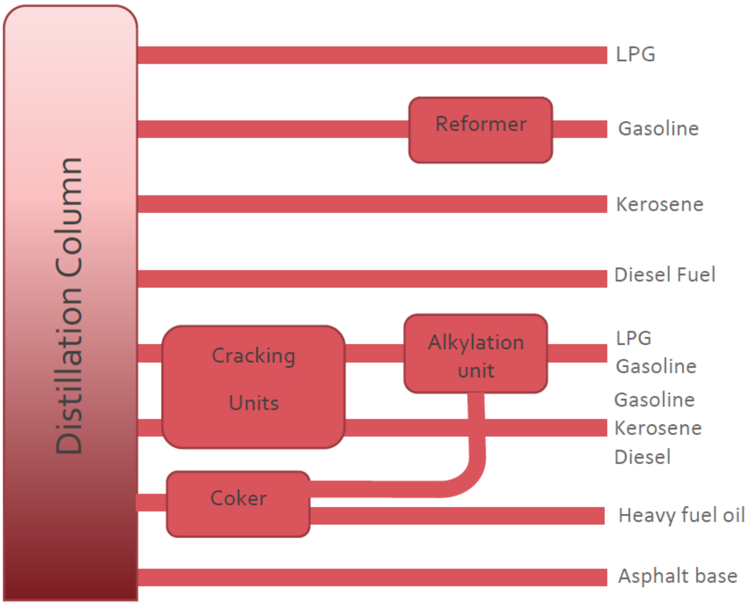

Figure 9: Diagram of oil refinery distillation process [8]

Waste energy streams from petrochemical refining are hot products and waste steam at low or medium pressures at medium (300-500°C) or low temperatures (<200°C). The hot streams are frequently used to heat incoming feedstocks using heat exchangers.

Other chemical manufactures includes the production of ammonia, sulphuric acid, cyanides, chlor-alkali and polymers. These processes require significant amounts of energy and produce waste heat streams in the medium to low temperature.

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Food and Beverage

The food and beverage industry uses a numerous heat processes including baking, boiling, frying, drying, distilling, pasteurising and refrigerating. Despite the fact that most processes are at low temperature (<260°C), heat recovery can still be usefully applied to reduce energy use.

Pasteurisation is commonly used to reduce the number of pathogens in foods. The process consists on heating food or liquids to a temperature usually less than 100°C (Figure 10). Using heat exchangers to warm the incoming product is very common and increases very much the efficiency of the process.

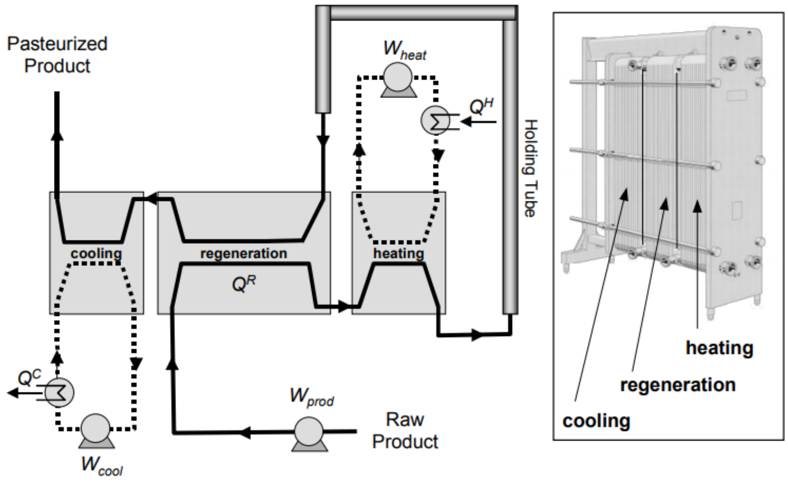

Figure 10: Schematic of pasteurization process [9]

Baking oven flues contain hot gases at temperatures over 200° which may be used easily to heat the combustion air entering the oven, reducing the amount of energy required. On the contrary, gases from frying processes contain vapours that make the use of heat exchangers quite difficult, so a solution may be recycling frying vapours directly mixed with the combustion air pre-heating the entering stream and reducing the energy needed (Figure 11).

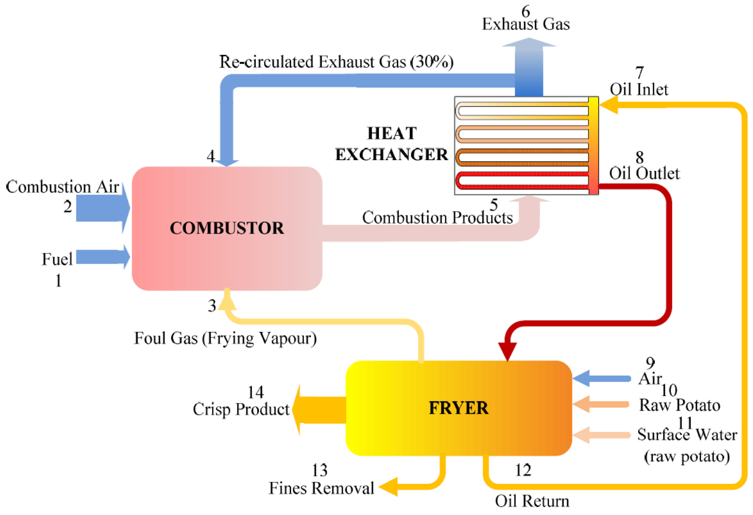

Figure 11: Schematic diagram of frying system [10]

There are also numerous opportunities to use waste heat for space and water heating or use it combined with heat pumps increasing its performance and obtaining heat at higher temperature.

Paper, pulp and printing

The main chemical pulping process in use is the Kraft process, whose diagram is shown in Figure 12. Chipped wood is cooked in a digester, mixed with several chemicals, at 170°C to degrade the wood fibres. The pulp fibres are then removed, washed, screened, bleached and dried for paper making.

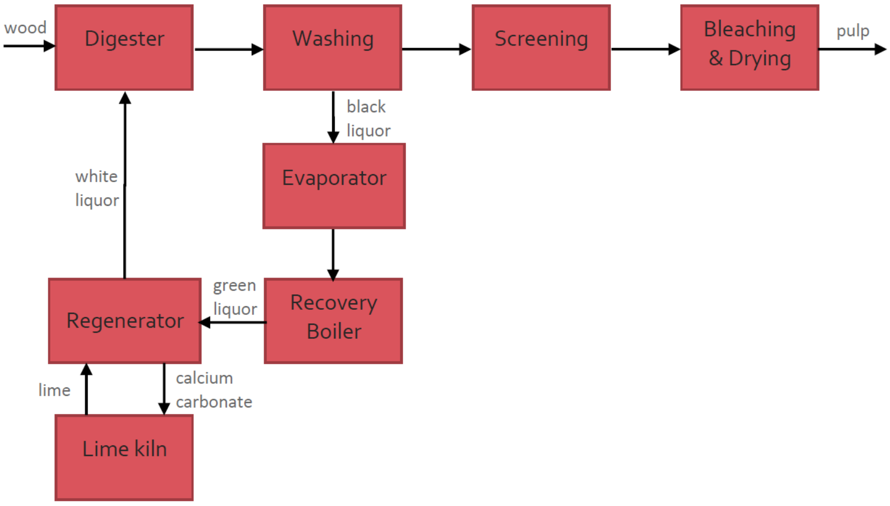

Figure 12: Diagram of the Kraft pulp making process [8]

Tree bark and rejected pulp from the screening progress are often burned at paper mills to produce power and steam used in the processes. Coupled with energy from the energy recovery boiler this can allow the process to be self-sufficient or even a net generator of energy.

There are opportunities to recover energy from exhaust steam from the cooking and evaporating processes as mentioned above for different sectors, but also to use heat exchangers to heat air entering the drying process with outgoing air or with low grade steam.

Iron and steel

Iron and steel making processes are usually divided in two types depending on the origin of the feedstock material used. Blast furnace and basic oxygen furnace (BF-BOF) route uses mainly virgin ores, while electric arc furnace (EAF) route re-melt scrap and alloys. Figure 13 describes these two major process routes.

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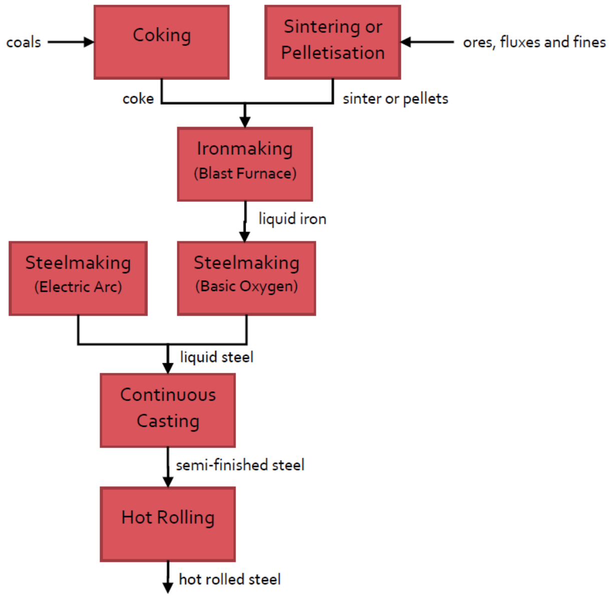

Figure 13: Diagram of iron and steel process route [8]

Some studies notes that up to 25% of the EAF input energy may be recovered to produce steam for power generation but this is rarely practised due to the harsh environment of the fume system and intermittent nature of the process.

Steelmaking processes are by nature high temperature and produce a number of hot gases streams which are particularly suited to heat recovery. Heat energy is commonly recovered to either preheat combustion fuel and air or to produce steam. Kinetic energy is also commonly recovered from blast furnace exhaust gas flows using a low pressure turbine. This industry produces hot steel products at high temperatures, over 700°C, from which very little energy is recovered due to the lack of cost effective practical technologies although projects to address this have been carried out or are ongoing.

Figure 14: Steelmaking plant. Source: Shutterstock

Most steelmakers use heat recovery in parts of their process routes; however, heat recovery solutions implemented across all steps of the route are not common. In this industry, economic payback and capital availability rather than technical feasibility typically limit the adoption of heat recovery solutions.

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Power and energy

Combined heat and power stations are often used on oil refinery and paper pulp production plants to provide process heating and steam for industrial processes or heat for space heating through district heating schemes (Figure 15).

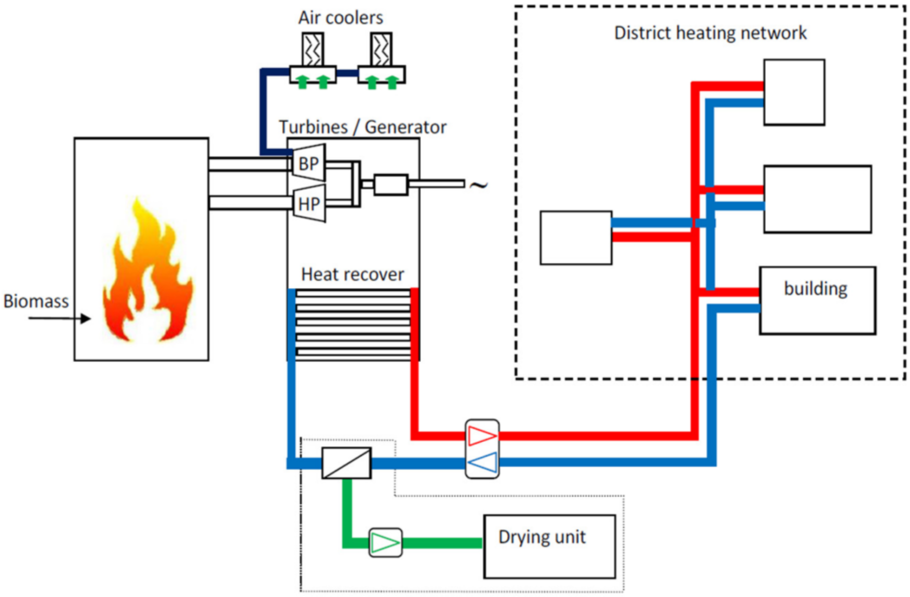

Figure 15: Schematic diagram of a cogeneration facility linked to a district heating network [12]

Waste heat energy from electricity production is mainly at temperatures less than 100°C and the rest at intermediate temperatures between 100 and 300°C. This low-grade energy is useful for space heating or recovery using ORC machines.

Europe has a long history using energy from waste both for district heating and combined heat and power plants. Traditional technologies make the incinerator to handle temperatures between 1,000 and 1,300°C, so that the hot exhaust gases can be used to produce steam for electricity generation and then heat may be used for heating water or space heating.

Modern plants using waste to generate electricity may adopt pyrolysis or gasification technologies producing carbon monoxide and hydrogen gases that may either be burned or used as inputs for other industrial processes.

Other industries

Most of the waste heat streams from other industries not described above, such as transport and machinery manufacture, textiles, mining, construction and wood processing, are assumed to be at temperatures less than 200°C which tend to be used in space or district heating applications.

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3 Recovery of waste cold

The main source of waste cold energy found in the literature is that released during the regasification of liquefied natural gas (LNG). This gas in liquid state is transported to consumer countries at a temperature of -160°C. Regasification energy may be harnessed to produce electricity either by driving generators by the direct energy of gas expansion or by using ORC machines. There exist some projects that study building a complete cold economy where waste cold recovery is a key technology (Figure 16). The cold from LNG regasification can also be used to improve the efficiency of some distillation facilities or cool the input of compressors systems in order to increase their efficiency.

Another interesting system with which waste cold recovery can be implemented is fifth generation district heating and cooling networks. In these networks cold water is pumped to customers who require coolant for equipment of air conditioning. Absorption chillers using waste heat are commonly used to generate cold during warmer seasons which is transported through the network to the users. Conventional heat pumps can also be used in these networks as boosting devices to achieve the correct temperature of use with very high efficiency and reduced energy consumption.

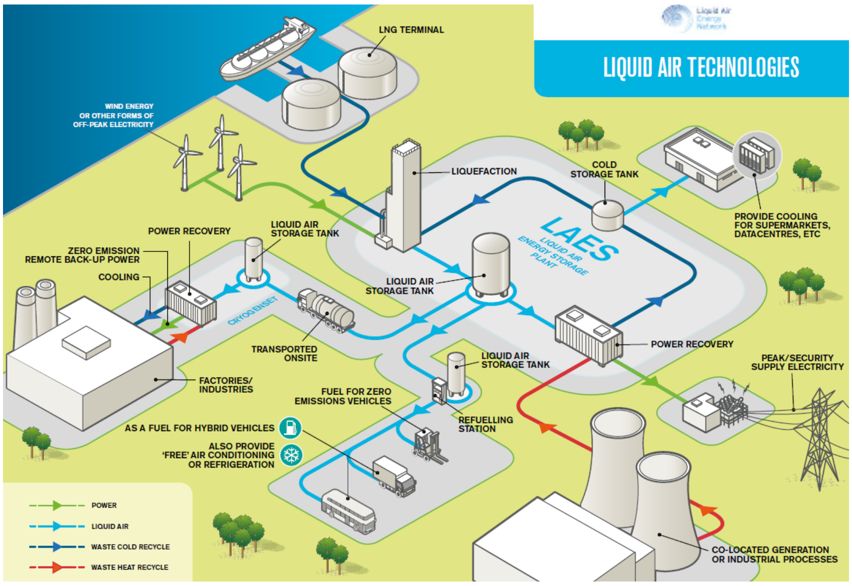

Figure 16: Diagram of potential of cold economy [13]

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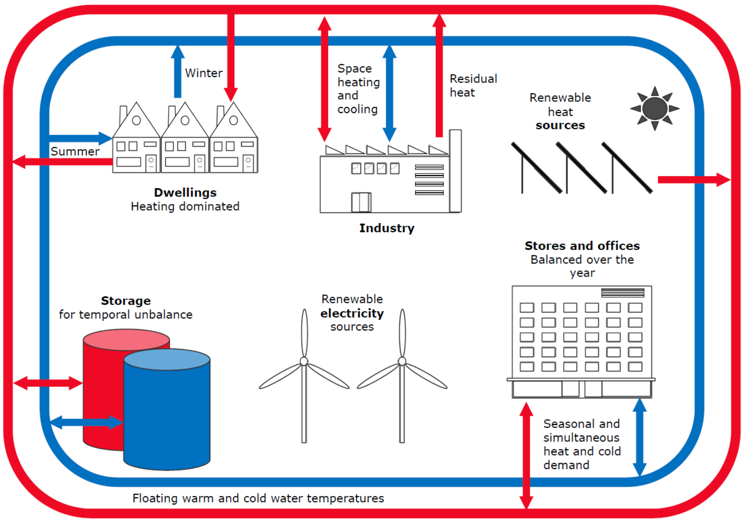

Figure 17: Fifth generation district heating network. [14]

4 End use of recovered waste heat

Regarding the final use of recovered industrial heat, its use can be classified in two possible ways: internal use or external use. When the internal use is considered, the industrial facility itself where the waste heat is recovered will transforms and consumes the recovered energy, whether it is in the form of heat or it is transformed into other forms such as refrigeration or even electrical energy. Direct recovery to the original process or recovery with transfer to a second process within the original production facility can be considered in this category. In Figure 18, energy balances of both types of internal recovery are represented.

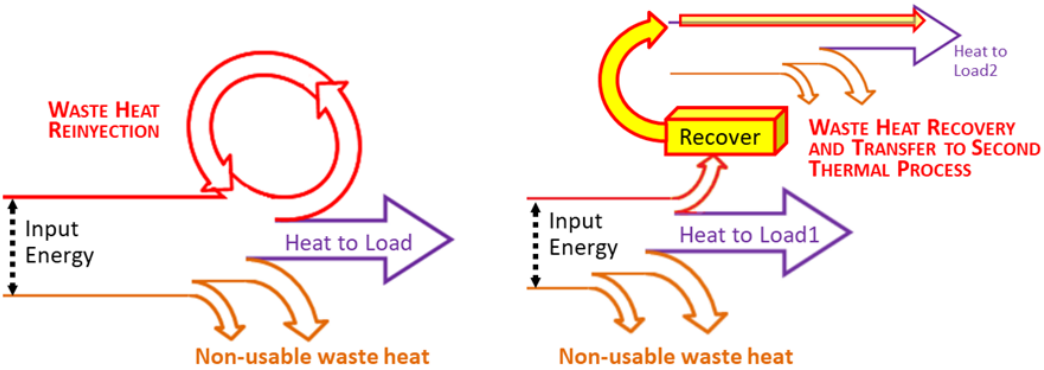

Figure 18 Schematic representation of direct WHR (left) and inter-process WHR (right) [2]

The main advantage of the direct WHR is that the temporal synchronization (matching) between the production of waste heat and its reuse is naturally guaranteed, whereas in the reuse in another process of the factory certain simultaneity of both processes must be ensured.

In the external use – represented in Figure 19 –, which is often explored when the waste heat cannot be used internally in the origin facilities, the waste heat can be used by third parties such as administrative, commercial or residential buildings or even other industries. In this case, the first challenge is the adjustment or synchronization of the potential waste heat and the demand.

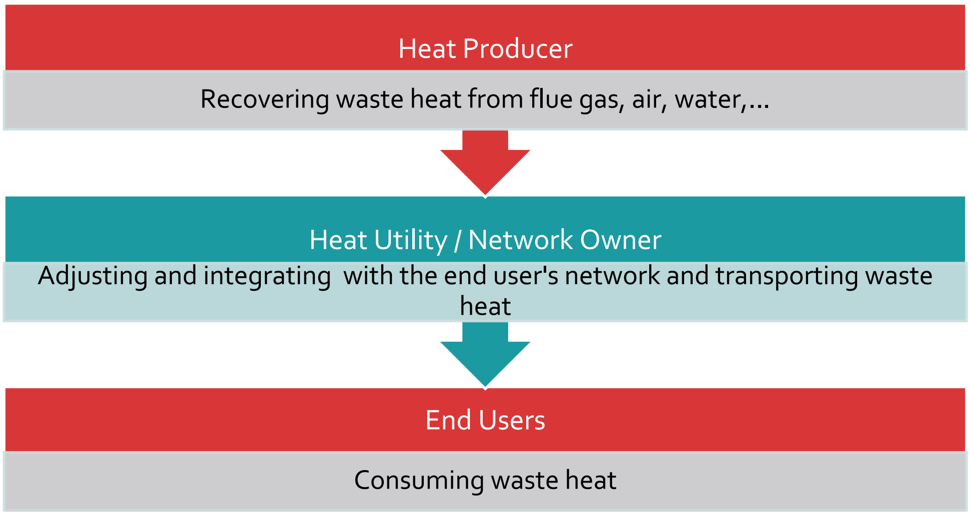

Figure 19 Schematic representation of an external use of WH recovery case. [2]

In this external use case there is the possibility of introducing intermediate actors (ESCOs) between heat producers and end users of the recovered waste heat. An intermediate ESCO finances the installation of heat recovery systems in the factory and remunerates the heat producer for the recovered heat which is supplied to the heat utility or the owner of the heat network, which pays to the ESCO for the corresponding energy supply (Figure 20).

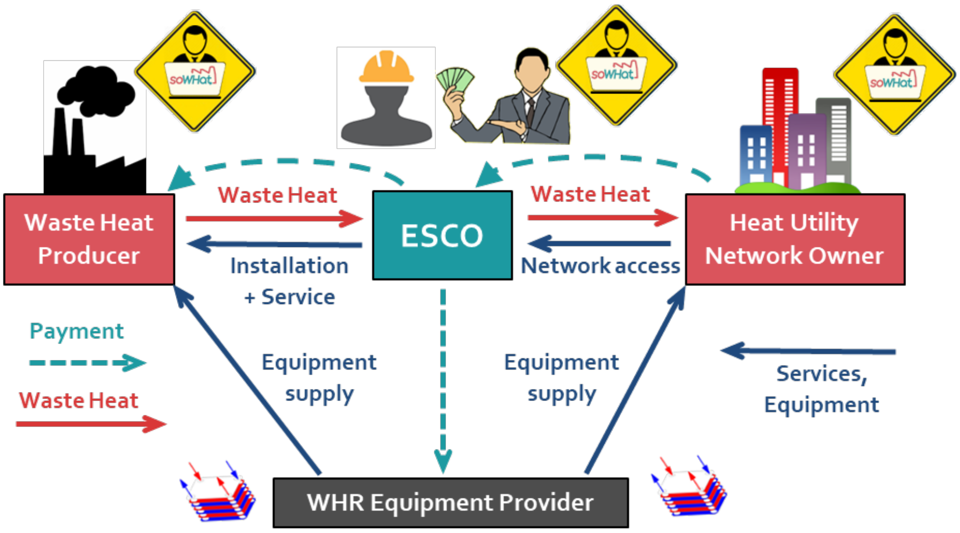

Figure 20: Schematic representation of a business model of a case of ESCO as an intermediary in an external use of WH recovery [2]

The greatest challenge to implement a WHR scheme is finding the “end use” for the recovered heat. Some of the questions that must always be asked before considering the design of a WHR project could be the following: Where will you use the recovered heat?, Is the heat sink close or far from the waste heat source?, Is the heat sink appropriate for the heat source temperature?, Will heat sink and heat source operate at the same time, all the time?, Will its volume vary considerably, and often?

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