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EU PAPER: ORC WASTE HEAT RECOVERY IN EUROPEAN ENERGY INTENSIVE INDUSTRIES

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1. INTRODUCTION

A considerable amount of heat is wasted in many industrial plants employing thermal processes. Many industrial processes need a cooling system, like in the treatment of exhausted gases. This equipment involves additional investments and operation and maintenance costs. Waste heat recovery solutions have been developing since many years, both for thermal users and power generation. If certain quantity and quality requirements of the waste heat are met, it can be economically convenient to install an Organic Rankine Cycle (ORC) – a closed cycle working with an organic fluid in order to produce electricity. In the last ten years, many ORC turbines have been installed to recover heat from industrial processes, such as cement kilns, metallurgy processes, flat glass plants, gas turbines and internal combustion engines. This application can be considered an excellent example of energy efficiency measure, because companies that have made these investments have reduced their electricity consumption, with no additional use of primary energy. Please find below a simplified scheme of a heat recovery system (fig. 1).

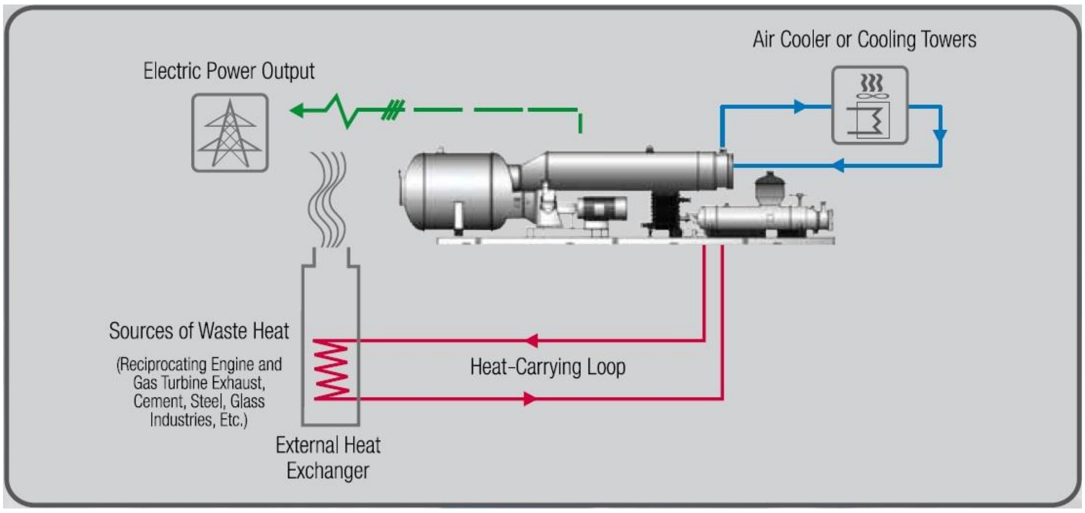


Figure 1: heat recovery scheme

On January 2010 the first European project on mapping the potential for heat recovery with ORC systems in energy intensive industries (in a pilot area) started. This project, funded by the LIFE + program (LIFE08 ENV/IT/000422 acronym "H-REII"), had the goal of promoting policy and governance actions that would support waste heat recovery for power generation in energy intensive industries and quantify the potential CO2 savings. The HREII DEMO project (LIFE10 ENV/IT/000397) is the continuation and implementation of the H-REII project aiming at:

- **developing the first prototype of ORC heat recovery plant from EAF (Electric Arc Furnace)** in the steel industry completely integrated in a fumes treatment cleaning system;
- **promoting EU policy and governance actions for incentivizing waste heat recovery** for power generation, reducing CO_2 emissions by the valorization of process effluents in Energy Intensive Industries.

Waste heat recovery for power generation (WHRPG) in energy intensive industries by means of ORC is technically feasible: WHRPG plants with ORC technology are operating in the cement, steel and glass industry and in the natural gas transmission and storage sector. An evaluation of the potential electricity generation with this technology was carried out at European level. Industrial processes considered are: clinker production in the cement industry, Electric Arc Furnaces (EAF) and reheating furnaces for hot rolling mills in the steel industry, flat glass furnaces and gas turbines in gas transmission and storage sector. It has been estimated a theoretical potential of about 2.5 GW of ORC gross power. The heat source is provided by the industrial process, whose operating hours depend on the market fluctuations. Considering 8 000 operating hours a year, ORC plants can generate almost 20 TWh of electric energy. This value represents the 4.8% of the total electricity consumption of EU industry in 2009 and implies avoided emissions of almost 7.5 million tonnes of carbon dioxide [1].

Moreover, ORC manufacturer are developing waste heat recovery projects in other industrial processes, particularly in metallurgy.

[1] Considering different emission factor for every EU members: Source: European Environmental Agency, 2010

Process	Heat source temp [°C]	P_{sORC} [kW/t]	Plants	ORC Power [MW]
Flat Glass	500	2.33	58	79
Clinker Prod.	350	1.01	241	574
EAF	250[2]	27.8	190	438
Rolling mills	400	6.87	209	310
GCS		30%[3]	500	1 155
Total				**2 556**

Table 1: ORC potential in EU energy intensive industries

Sectors	Energy Recovery [GWhh/yr]		Emission avoided [10^3t CO_2/yr]	
	5000h	**8000h**	**5000h**	**8000h**
Flat Glass	393	628	140	225
Cmnt	2 870	4 592	1 213	1 940
Steel	3 740	5 984	1 351	2 162
GCS	5 775	9 240	2 062	3 299
EU 27	**12 778**	**20 444**	**4 766**	**7 626**

Table 2: Energy generated from waste heat recovery and emission savings in EU27 industries

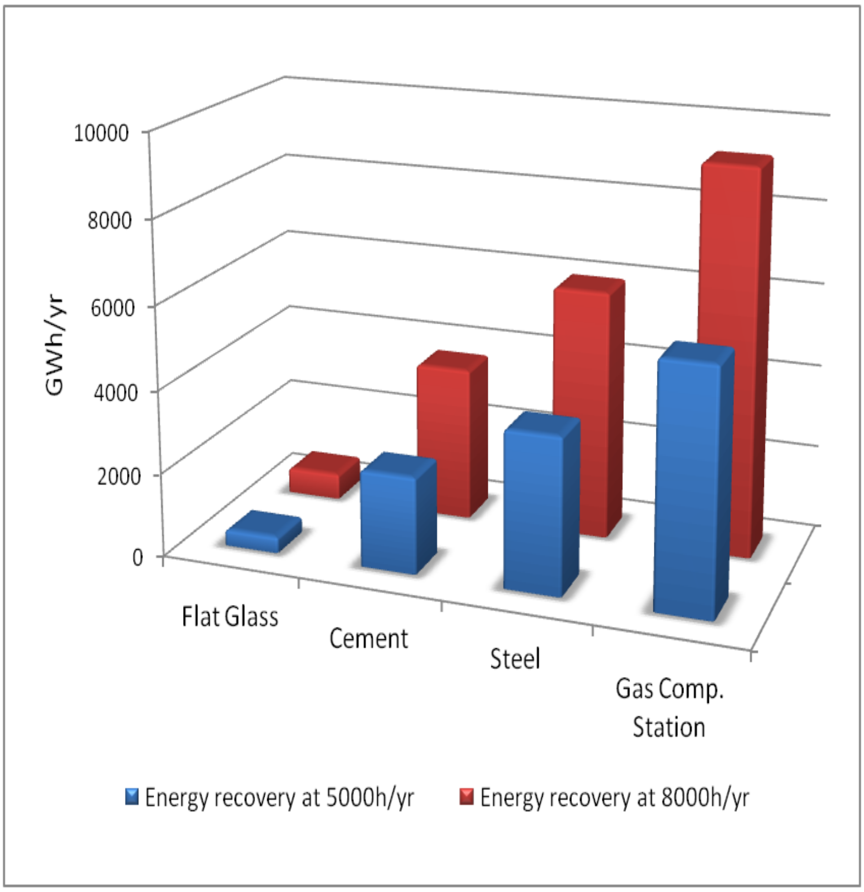


Figure 2: Annual energy recovery in EU27 industries

[2] Steam from heat exchanger
[3] Percentage of Gas Turbine Power

2. WASTE HEAT RECOVERY IN EU27 CEMENT PLANTS: ESTIMATE ON ORC POWER

Country	No. plants	Nominal Capacity [Mt/year]
Spain	38	48.3
Italy	59	38.6
Germany	33	28.8
France	31	21.6
Greece	8	14.5
Poland	11	14.0
Portugal	6	10.8
UK	12	10.4
Others	61	60.8
Total EU27	**259**	**247.8**

Table 3: EU27 cement plants location and capacity

Country	Daily capacity [10^3t/day]	r_P [(MW·day)/t]	P_{ORC} [MW]
Italy	111.7	0.75	86.7
Germany	69.8	1.01	70.3
Spain	116.5	1.01	117.3
France	49.6	1.01	49.9
UK	25.1	1.01	25.3
Belgium	10.7	1.01	10.7
Austria	10.4	1.01	10.5
Czech Rep.	12.7	1.01	12.8
Others	189.3	1.01	192.5
Total EU27	**595.9**		**575.9**

Table 4: ORC power estimate for EU27 cement factories

Over 576 MW of ORC power can be installed in EU27 cement industry (see Tab.4). The annual energy recovery was also estimated assuming a range between 5000 and 8000 operating hours per year, in order to consider variations in cement production due to market fluctuations. This energy recovery allows avoiding the purchase of electricity from national grid and the consequent greenhouse gasses emissions (see Tab.5). Considering only **EU27 cement plants, an amount between 2.87 and 4.59 TWh per year can be generated from waste heat recovery**, around 0.46% of the electricity consumption in European Industry in 2010. The corresponding average value of CO_2 avoided emissions, equal to almost 1.5 million metric tons, represents the 0.44% of the total amount of CO2 emitted in 2010 by EU27 industry. There are many factors to take into consideration for further developments in ORC applications in EU27 cement industry: (i) global trend in cement production, consumption and trade, with the increasing importance of developing countries as market players; (ii) energy efficiency policies, supporting such installations; (iii) the increasing interest in alternative fuels, affecting the economic energy scenario.

Country	Energy Recovery [GWh/yr]		Emission avoided [10^3t CO_2/yr]	
	5000h	**8000h**	**5000h**	**8000h**
IT	433	693	175.5	280.8
GE	351	562	176.7	282.7
ES	586	938	252.1	403.4
FR	250	400	23.0	36.8
UK	126	202	62.7	100.3
BE	54	86	13.6	21.8
AU	52	84	8.4	13.5
CZ	64	102	40.3	64.5
Oth	953	1 525	460.2	736.4
EU 27	**2 870**	**4 592**	**1 212**	**1 940**

Table 5: Power generated from waste heat recovery and emission savings in cement industry

3. WASTE HEAT RECOVERY IN EU27 STEEL PLANTS: ESTIMATE ON ORC POWER

Country	No. EAF	Capac. [Mt/yr]	No. Rolling mills	Capac. [Mt/yr]
Italy	40	23.4	63	35.8
Spain	29	18.5	42	21.8
Germany	27	16.7	52	50.8
France	20	7.6	38	31.3
UK	8	4.9	31	15.9
Poland	9	4.5	19	9.7
Belgium	7	4.7	9	16.6
Romania	6	3.2	12	9.0
Greece	5	3.5	6	3.2
Czech Rep.	9	0.5	12	7.4
Others	30	14.0	78	50.2
Total	**190**	**101.7**	**362**	**251.8**
Idle	11		14	

Table 6: N. and nominal capacity of EU27 EAF and rolling mills

In the steel sector, ORC application is considered most suitable for recovering exhaust gasses from Electric Arc Furnaces (EAF) and from rolling mills.

Potential recovery and savings are reported in Tab. 8. In view of 190 installations in EAFs and 209 in rolling mills, it has been estimated a **power generation from waste heat recovery between 3740 and 5984 GWh every year**: around 0.58% of the final electricity consumption of EU27 industry in 2010. **Avoided emissions of CO_2 are between 1.351 and 2.162 million tonnes**.

WHRPG in the steel industry with ORC unit has been adopted in two processes. On February 2013, Turboden srl started up **the first ORC that recovers heat from exhausted gases of a reheating furnace in hot rolling mills**. This plant is located in Singapore, but it is very similar to most of the rolling mills spread all over the world. The exhausted gases are clean enough to allow the direct exchange with the organic working fluid, thus the required investments are lower. The ORC net power installed is 700 kW. This case can be replicated for all hot rolling mills, both those at the bottoming of integrated steel plants (blast furnace and converter shop) and those at the bottoming of electric arc furnaces.

A new interesting scenario is represented by waste heat recovery from Electric Arc Furnaces. The first ORC unit for this application is starting up by the end of 2013, in the Feralpi Group plant of Riesa, Germany. A special heat exchanger has been designed to produce 30 tons per hour of steam at 27 bar and 245 °C. 10 tons per hour are delivered to an industrial plant, the remaining part is employed by an ORC unit of about 3 MW, thus this system can be considered a combined heat and power plant. The EAF is not a continuous process: thermal flow varies during the melting cycle and while the scrap material is loaded into the basket there is no thermal power available. In order to solve the thermal power availability, heat absorber are installed and, considering power generation, the ORC properly operates with a steam flow rate between 2 and 22 tons per hour, automatically adapting its operation to the different operating conditions, a performance that traditional steam plant cannot achieve. This plant is part of the H-REII DEMO Project (Heat Recovery in Energy Intensive Industries), co-financed by the LIFE + program of the European Commission DG Environment for the high technological and environmental value. Many others applications are expected to follow.

Country	ORC Power in EAF [MW]	ORC Power in rolling mills [MW]	Total ORC Power in EU27 steel ind. [MW]
Italy	92.9	21.7	114.6
Germany	74.0	82.2	156.2
Spain	85.8	25.6	111.3
France	43.1	30.1	73.2
UK	27.7	19.7	47.4
Belgium	25.7	28.7	54.5
Austria	4.2	12.2	16.5
Czech Rep.	0.8	9.2	10.0
Others	83.3	81.0	164.3
Total EU27	**437.5**	**310.5**	**748.0**

Table 7: ORC gross power to install in EU27 steel industries

Country	Energy Recovery [GWhh/yr]		Emission avoided [10^3t CO_2/yr]	
	5000h	**8000h**	**5000h**	**8000h**
IT	572	916	206.9	331.0
GE	781	1 250	343.5	549.6
ES	557	891	184.1	294.6
FR	365	583	28.8	46.1
UK	237	379	102.2	163.5
BE	272	436	66.8	107.0
AU	82	132	11.2	17.9
CZ	50	80	27.2	43.5
Oth	824	1 318	380.5	608.8
EU 27	**3 740**	**5 984**	**1 351**	**2 162**

Table 8: Energy generated from waste heat recovery and emission savings in EU27 steel industry

4. WASTE HEAT RECOVERY IN EU27 GLASS PLANTS: ESTIMATE ON ORC POWER

Glass industry is divided depending on the manufactured product. **Only flat glass plants have been considered** because energy audits for container glass are not available. Despite the cement and steel cases, it was not possible to access to a database with data for every single glasswork. We mainly referred to BREF for glass manufacturing, related to the 2007-2008 period. This document reports the number of furnaces placed in EU27 (Tab. 9) and their proportion divided into ranges of daily production (Tab. 10). For every range we calculated an average size as shown in Tab.11, for a **total gross ORC power of 78.5 MW with 58 installations**. An **energy generation from waste heat recovery has been estimated from 392.6 GWh to 628.2 GWh per year and avoided emissions of carbon dioxide from 140333 to 224533 tonnes**.

Country	No. plants	Product. [10^3t/yr]
Germany	11	1,425
France	7	907
Italy	7	908
Belgium	7	907
UK	5	645
Spain	5	645
Poland	3	390
Portugal	1	127
Other	9	1,545
Total	**58**	**7,500**

Table 9: EU27 flat glass plant distribution and production

t/day	%	No. of plants
< 400	1%	1
400 – 550	37%	22
550 – 700	48%	28
>700	14%	7
Total	**100%**	**58**

Table 10: EU27 flat glassworks production ranges

Range	Capacity [t/day]	ORC Power [kW]	No. Plants	Total ORC power [MW]
<400	350	1 040	1	1.0
400-550	475	1 040	22	22.9
550-700	625	1 500	28	42.0
>700	750	1 800	7	12.6
Total flat			**58**	**78.5**

Table 11: ORC power to install in EU27 flat glass industry

5. WASTE HEAT RECOVERY IN EU27 GAS COMPRESSOR STATIONS: ESTIMATE ON ORC POWER

Country	Gas turbines power [MW]	Power corrected [MW]	ORC Power [MW_e]
Germany	2 000	585	176
UK	1 455	426	128
Italy	500	146	44
France	650	190	57
Netherland	900	263	79
Spain	412	121	36
Austria	352	103	31
Belgium	116	34	10
Slovakia	19	6	2
Ireland	94	27	8
Poland	350	102	31
Czech Rep.	297	87	26
Hungary	187	55	16
Finland	13	4	1
Bulgaria	214	63	19
EU 27	**7 559**	**2 211**	**664**
Russia	43 400	12 695	3 808
Ukraine	5 450	1 594	478
Norway	150	44	13
Total Europe	**56 559**	**16 544**	**4 963**

Table 12: Gas turbine power and ORC power in gas compressor station

Natural gas transmission infrastructures are typically based on gas turbine (GT) units, used to accomplish natural gas compression in Gas Compressor Station (GCS), placed around every 100–200 km, in order to maintain gas pressure on average around 70 bar, but with cases typically in the range 40–120 bar. Their distribution is depicted in figure 3. Also in Gas Storage Fields (GSF) gas is inserted into the infrastructure by means of gas turbines. These stations use a part of the conveyed gas; the GCS is typically made up of at least two GTs, one of those plays a backup role. GCS can be divided in base load stations, which work continuously, approximately 8000 h per year, and seasonal stations, located in warm regions, working less than 4000 h per year. To exclude backup units (usually one over three GTs) a reducing coefficient of the installed power equal to 0.65 was adopted. In order to consider only base load stations, a cautionary additional coefficient of 0.45 was adopted. ORC power was estimated as a 30% of the corrected GT power. Results are reported in Table 12. Excluding Russia, 1304MW ORC gross power can be installed in EU27 gas plants, with electricity generation up to 10.43 TWh per year and avoided GHG equal to 3.7 million metric tons.

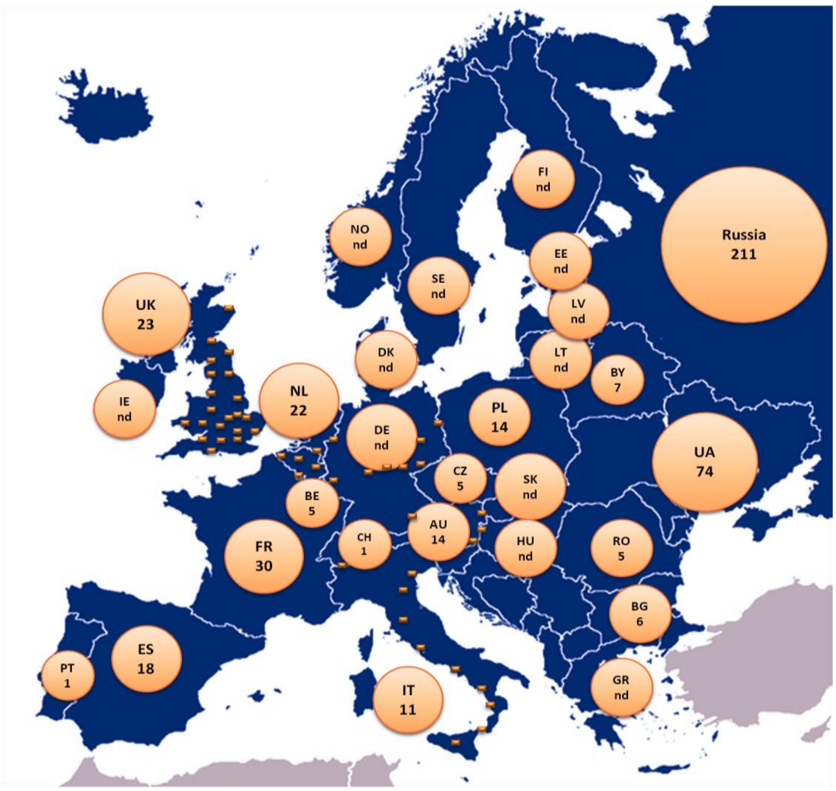


Figure 3: European gas compressor station distribution. [Source: www.naturalgas.org]

6. CONCLUSIONS

Europe is a global leader in developing low carbon and energy efficiency solutions in a wide range of sectors (e.g. energy efficiency technologies and services, energy management system) but the diffusion of such technological solutions is limited for different reasons: technological and not-technological barriers have adversely affected the introduction of more sustainable and more energy efficient systems that allow to recover heat for power generation in the energy intensive industries.

At current trend, EU target of 20% reduction of final energy consumption compared to projections for 2020 with energy efficiency practices will not be met, thus heat recovery represents an opportunity in industry to recover energy. Among heat recovery technologies, ORC systems are increasing its possibilities to be adopted in different industries.

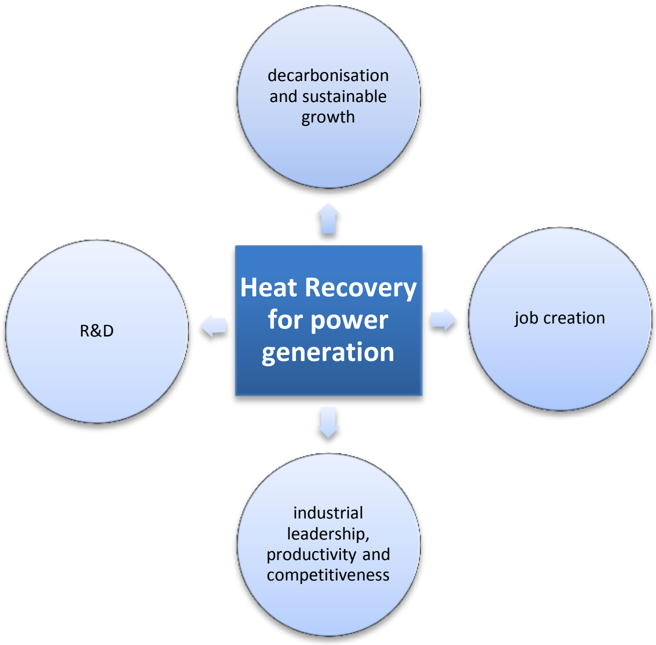


Figure 3: Heat recovery benefits.

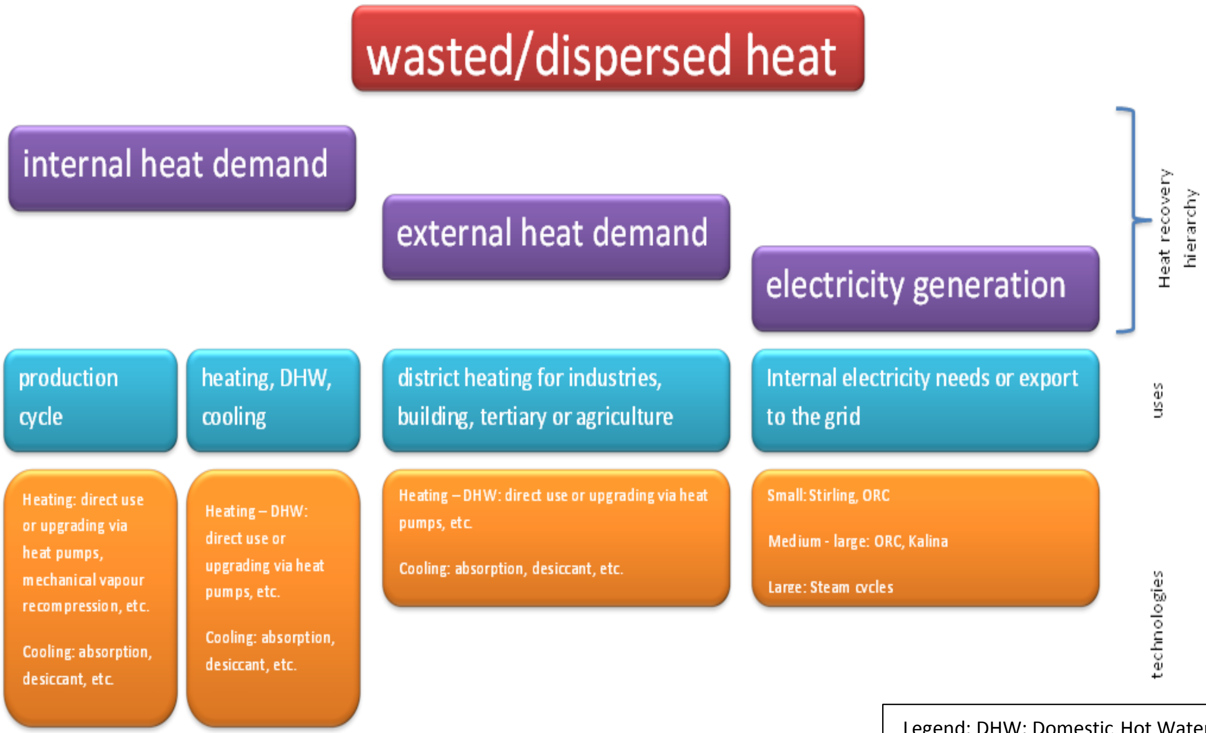
In order to take these opportunities, the European Union could evaluate the introduction of new policies to promote and incentive heat recovery in the energy efficiency policies framework for an over-all benefit:

- decarbonisation and sustainable growth: heat recovery can increase the environmental and energy sustainability of the industrial processes, and also contribute to reduce GHG emissions; power is generated through the waste heat recovery without using any fuels;
- job creation: (i) *jobs in the manufacture of waste energy recovery equipment*: these employers range from large multinational corporations to small, specialized firms; (ii) *jobs in creating on-site "energy islands" in host facilities* including welders, pipefitters, design engineers and construction workers; (iii) *jobs in operating on-site energy islands*; (iv) *jobs resulting from increased competitiveness*.
- industrial leadership, productivity and competitiveness: heat recovery as an instrument of industrial policy to boost competitiveness and investments in the manufacture sectors, it's able to collect different industrial actors; it's possible to foreseen a potential investment of 8 billion euro in the new sector of heat recovery in the EU.
- R&D: Important results would be reached with the introduction of innovation policies in order to increase and coordinate European R&D spending to support promising technologies in energy intensive industries.

To put into effect the above mentioned benefits, some measures should be considered by European institutions and Member States.

Firstly, the lack of certain and long-term EU regulatory framework and targets for energy efficiency could hinder the development of a European energy efficient market. The new energy efficiency directive is a step towards the good direction but it's necessary that Member States during the implementation phase consider the potential of heat recovery applications, especially referring to article 8.7[4] and article 14[5]: compulsory energy audits and supported waste heat recovery for power generation system, whenever the ones are technically and economically workable, could catalyze investment in the energy efficiency market, helping to reach the objective of 20% reduction in energy consumption. The figure 4 depicts the priority in the utilization of waste heat recovery.

Moreover during the energy audit, special attention should be placed in the gas cooling - often compulsory before the waste gas treatment - because it is possible to put heat exchanger(s) and a Rankine cycle, instead of adding air to cool down. In this way the electricity consumption of the waste treatment can be covered.



Legend: DHW: Domestic Hot Water

ORC: Organic Rankine Cycle

Figure 4: Waste heat recovery priority

Secondly, the economic obstacle is a key issue: investment payback time for the implementation of technologies related to WHR to electricity generation are usually too long for the industrial sector, for this reason the creation of *ad hoc* incentives mechanism or the inclusion in existing supporting schemes (e.g. white certificates) could help in overtaking this barrier. Considering the role played by the energy intensive industries in the overall energy consumption, the **European Union should increase a specific provision to finance investments in WHRPG, as it mentioned in European Investment Bank (EIB) Energy Lending Criteria**[6].

Last but not least, it is necessary **to increase the awareness - through an intensive dissemination campaign**, a proper education and training path - of the energy efficiency potential of the waste heat recovery system in the industrialists' mind as a solution to raise investments, to create jobs and to boost sustainability.

The widespread ORC systems are proved reliable in the biomass and geothermal applications, but they are **still uncommon in the industry**. The above mentioned proposals could foster the technology as an energy efficiency measure, repeating the positive results already obtained with biomass and geothermal.

[4] Directive 2012/27/UE, article 8.7: "Energy audits may stand alone or be part of a broader environmental audit. Member States may require that an assessment of the technical and economic feasibility of connection to an existing or planned district heating or cooling network shall be part of the energy audit.
Without prejudice to Union State aid law, Member States may implement incentive and support schemes for the implementation of recommendations from energy audits and similar measures".

[5] Directive 2012/27/UE, article 14.5 lett. c: "an industrial installation with a total thermal input exceeding 20 MW generating waste heat at a useful temperature level is planned or substantially refurbished, in order to assess the cost and benefits of utilizing the waste heat to satisfy economically justified demand, including through cogeneration, and of the connection of that installation to a district heating and cooling network".

[6] European Investment Bank, EIB Energy Lending Criteria, p. 33, 2013