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ORC Waste Heat Recovery for a more Competitive and Sustainable Steel Industry

Policy paper

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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.

In figure 1 is reported a simplified scheme of a heat recovery system.

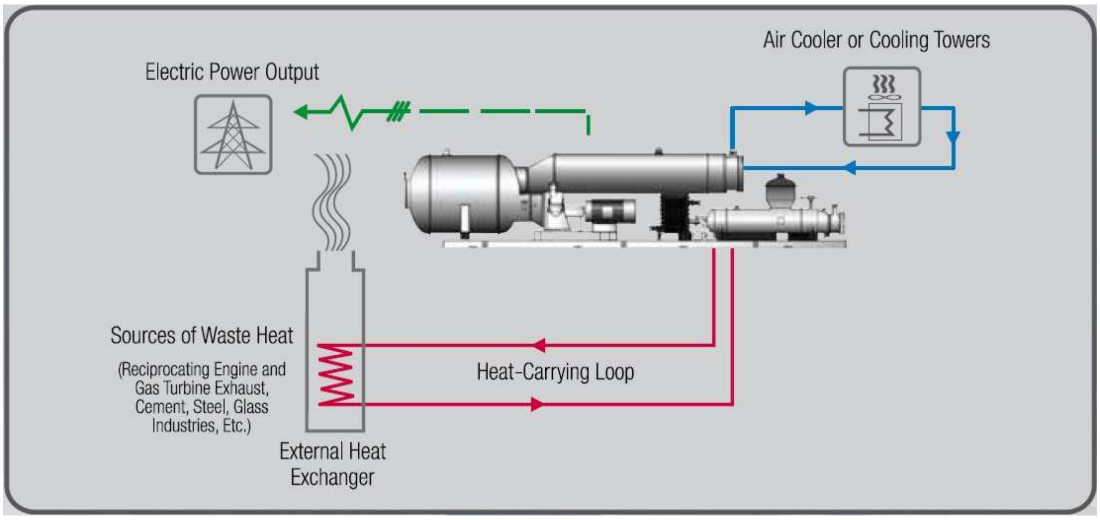

Figure 1: heat recovery scheme

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 quantifying the potential CO_2 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[1]. 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

1 See Ademe Report, Waste Heat Recovery for Power Generation, October 2012

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[2] and implies avoided emissions of almost 7.5 million tonnes of carbon dioxide[3].
Moreover, ORC manufacturer are developing waste heat recovery projects in other industrial processes, particularly in metallurgy. This paper will focus mainly on steel sector.

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

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.

The other WHRPG application in the steel sector is from the Electric Arc Furnaces exhausted gases. As previously mentioned, 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.

190 EAFs are located in EU27, 11 of which are currently (July 2012) idle (Tab.1)[4].
In order to estimate the potential ORC power, the most influent factor is the furnace capacity ("Tap weight") expressed in tons. EAF process lasts almost one hour ("tap-to-tap time"), thus furnace capacity can be considered as an hourly capacity of the plant. From the energy audit made within H-REII Demo project, we calculate an average ORC power of about 28 kW per ton of EAF capacity

While EAFs differences are mainly related to tap weight, in hot rolling mills, reheating furnace size depends on semi-finished product processed. In the HREII DEMO analysis only light, medium and heavy section mills, hot strip mills, wire rods mills and plate mills have been considered. VDEh Plantfacts Database provided data for 209 facilities. Based on six energy audits, an ORC potential of about 7 kW per ton hourly produced has been calculated.

Estimation on ORC gross power possibly installed in EU27 EAFs and rolling mills are detailed in Tab.2 Potential recovery and savings are reported in Tab. 3. Results are shown for 5 000 operating hours a year – a conservative value that reflects period of low demand, and 8 000 hours – a theoretical maximum. When taking into account the 190 installations in EAFs and 209 in rolling mills, it is assumed that every year, **an energy generation from waste heat recovery between 3 740 and 5 984 GWh has been estimated** and **emissions of CO_2 account between 1.351 and 2.162 million tonnes have been prevented**.

2 Intenational Energy Agency, World Energy Outlook 2011,

3 Considering different emission factor for every EU members: Source: European Environmental Agency, 2010

4 VDEh Plantfacts Database, 2012

Table 1: Number and nominal capacity of EU27 EAF and rolling mills

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[5]	251.8
Idle	11		14	

Table 2: ORC gross power to install in EU27 steel industries

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 3: Energy generated from waste heat recovery and emission avoided in EU27 steel industry

Country	Energy Recovery [GWh/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

5 Available data on reheating furnace capacity available only for 209 out of 362 hot rolling mills.

3. CONCLUSION

The EU is the second largest producer of steel in the world, with an output of over 177 million tons of steel a year, accounting for 11% of global output. Steel also forms part of a number of industrial value chains and is closely linked to many downstream industrial sectors such as automotive, construction, electronics, mechanical and electrical engineering. It employs directly about 360 000 highly skilled people and it has a significant cross-border dimension: 500 production sites are split between 23 Member States, making it a truly European industry[6].

Energy intensive industries as the steel companies play a crucial role in the climate change policy. Sectors subject to the ETS are, on aggregate, bound to reduce by 2020 their carbon emissions by 21% from the level in 2005, compared with 10% for the non-ETS sectors. For steel, it implies a reduction of around 42% compared to Kyoto reference of the year 1990[7].

The EU Low-carbon Roadmap shows the path for reducing EU's CO_2 emissions by 80% by 2050. To the industry sectors, that would mean aggregate reductions of 34% to 40% by 2030 (considering assumptions of technology and fossil fuel price) and of 83% to 87% by 2050. The EU low-carbon Roadmap has recognized that very important investments will be needed to achieve these targets.

Further significant reductions can only be achieved by developing and deploying breakthrough technologies. In order to increment the environmental sustainability without hitting the competitiveness of the sector, waste heat recovery for power generation systems acts as a viable solution when it is properly supported. The possibility of producing electricity for self-consumption using a free source as the exhaust gas is likely to boost the competitiveness of the steel sector.

Figure 2: waste heat recovery benefits.

A detailed description of the waste heat recovery benefits is reported below:

- **decarbonisation and sustainable growth**: heat recovery can increase the environmental and energy sustainability of the steel processes, and it can also contribute to the reduction of GHG emissions; power is generated through the waste heat recovery without any fuel;

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6 European Commission, Action Plan for a competitive and sustainable steel industry in Europe, p. 16, 2013, http://ec.europa.eu/enterprise/sectors/metals-minerals/files/steel-action-plan_en.pdf

7 European Commission, DG ENTR, High-level Round Table on the future of the European Steel Industry Recommendations, 2013

- **job creation**: (i) jobs in the manufacturing 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) those in operating on-site energy islands; (iv) the ones resulting from increased competitiveness[8].
- **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 players; it's possible to foreseen a potential investment of EUR 8 billion in the new sector of heat recovery, 2 of them for investments in the steel.
- **R&D**: Important results would be reached with the introduction of innovative 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 investments in energy efficiency. The new **energy efficiency directive 2012/27/EU is a step towards the good direction** but it is necessary that Member States during the implementation phase consider the potential of heat recovery applications, especially referring to article 8.7 and article 14: compulsory energy audits and supported WHRPG systems, 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 3 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 – as it is possible to put heat exchanger(s) and a Rankine cycle instead of adding air to cool down. This way, the electricity consumption of the waste treatment can be covered.

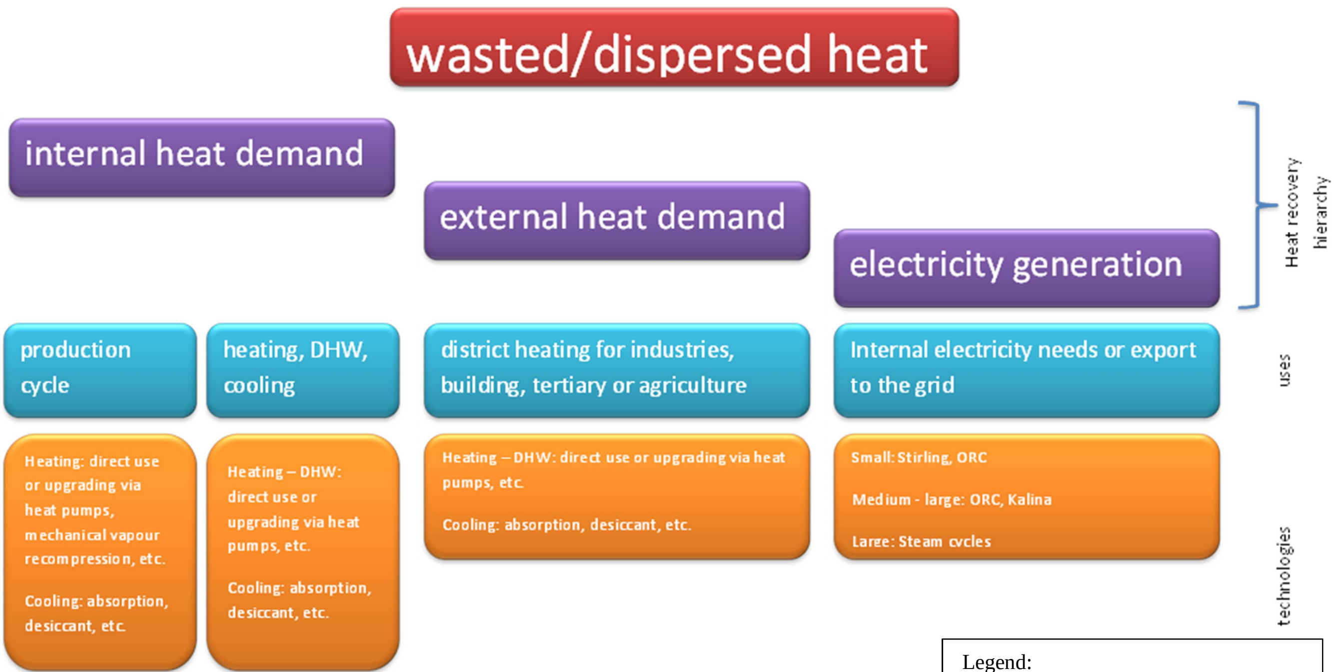

Figure 3: Waste heat recovery priority

Legend:
DHW: Domestic Hot Water
ORC: Organic Rankine Cycle

8 M. Lowe, G. Gereffi, Recycling Industrial Waste Energy, Chapter 7. Report prepared for the Environmental Defense Fund (EDF), Center on Globalization, Governance & Competitiveness (CGGC), Duke University, 2009

Secondly, the economic obstacle is a key issue: **investment payback times for the implementation of technologies related to WHRPG are usually too long for the steel sector**. For this reason, creating *ad hoc* incentives mechanism or including in existing supporting schemes (e.g. white certificates[9]) 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**[10].

On June 2013, the European Commission has presented the **Action Plan for a competitive and sustainable steel industry in Europe** in order to support the sector increasing its competiveness and sustainability. As mentioned by the plan: *«in the short term, [the European Commission] will promote energy efficiency (new boilers for power generation, gas recovery in steelmaking, Top-Pressure Recovery Turbine Plant (TRT),* ***waste heat recovery****) »* [11]. Furthermore, WHRPG can reduce CO_2 emissions generated from steel production without economic pressure and increase the sector competitiveness

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**. For the steel sector, the indicated proposals could foster the technology as an energy efficiency measure, repeating the positive results already obtained with biomass and geothermal.

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9 D. Di Santo, D. Forni, E. Biele, White Certificates for the industrial sector, FIRE, 2012

10 European Investment Bank, EIB Energy Lending Criteria, p. 33, 2013

11 See note 6.