A new Consteel® evolution with iRecovery®: better performances in steel production with heat recovery for district heating and ORC turbine power generation

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Summary
Ori Martin is making the revamping of the first European Consteel®, installed in 1998 in Brescia and still working with good performances, that now, after 16 years of continuous operation, needs to be revamped to increase flexibility and reduce consumptions. In addition to this, Ori Martin has also decided to install a heat recovery system on the primary off-gas line exiting the Consteel®, to recover the remaining thermal energy in the off-gas for the production of steam. The paper describes the improvements that will be done in the new Consteel® and the main technical features of the new iRecovery® system that will deliver thermal energy to the city of Brescia district heating grid during winter time and that will feed an ORC turbo-generator to produce electric energy for Ori Martin's internal use. The new installation will let Ori Martin to have one of the most environmental friendly and energy efficient steel melting system in the world.

Key Words
Consteel®, EAF, iRecovery®, heat recovery, waste heat boiler, ORC, district heating.

Ori Martin and the first Consteel® installation in Europe
Ori Martin group is specialized in the production of many specialty steel grades for automotive industry and demanding mechanical applications. The constant research effort allows the group to deliver now more than 200 steel grades to satisfy the needs of the European carmakers and to sustain profitability even in the most critical market conditions. The growth of the group throughout the years was led by both increasing the productivity and increasing the added value by integrating downstream processes, sustained by a deeply rooted commercial presence on the European market. The group keeps on investing in both product quality improvement and technological modernization, keeping the brand on the forefront of the most advanced producers. The first EAF, with a tapping size of 5 t, was started up in the early fifties of the last century. In 1965 the continuous caster has been installed, the second installed in Italy but the first one to enter in production. The example of Ori Martin led the development of the northern Italian minimills. In 1998, the group became the European pioneer in Consteel® EAFs, installing a new state-of-the art EAF fitted with the now widely spread Tenova continuous charging technology. The main goals of the project included the optimization the energetic efficiency utilization and the improvement of the environmental performance of the plant located near the very center of the city of Brescia, while keeping the production focused on the special steel grades and improving the product quality. The process results quickly outperformed the expected figures, as the operating team grown accustomed with the inherent reliability of the Consteel® EAF. Basing on this confidence, the Ori Martin team, backed by Tenova Engineering and Process departments, continuously improved the Consteel® that is now ready to grow into a new configuration to meet the new challenges of the market.

A new Consteel project
Since 1998, the scenario in which the original Consteel® operated has evolved considerably. Today it can be summarized as follows:

- the performance of the process is often in extreme conditions, where even a slight deviation causes increases in consumption, erosion of refractory and non-uniformity of the performance of the heat;
- the EAF and the Consteel® are no longer balanced and the feeding rate of the metallic scrap charge is often not able to reach the value required by the metallurgical process;
- the reduced content of carbon from the metallic charge limits the possibility to use the chemical energy as a means for melting;
- oxygen injection is limited to the minimum required to achieve target conditions at tapping keeping under control the oxidation of the charged scrap;
- the use of pig iron in the percentage of 20% of the total charge, as per the original design, is no longer sustainable;

- final product quality requires the consolidation of the use of numerous (and different) types of metallic charge, often containing deep drawing steel scrap as a nearly exclusive mix;
- the type of metallic charge used is not ideal for obtaining the maximum efficiency of heat transfer from the EAF off-gas to the scrap inside the Consteel® preheater because of its high reflectivity.

The operating results of recent times and the numerous tests carried out jointly by Ori Martin and Tenova, have highlighted the need to think about the design of a new Consteel®, which has as its objective the reduction of consumptions and improving the operational performances of the steel melting equipment in a scenario that requires a not common operational flexibility. The project of the new Consteel® is based on the following fundamental concepts:

- rebalance the two main components of the melting unit (Consteel® and EAF) to achieve efficiently and continuously the productivity goals;
- improve the thermal exchange between the EAF off-gas and the scrap in the different charging conditions (greater exposed surface and lower height of the scrap layer);
- improve the distribution of scrap entering the liquid steel bath (larger surface area where scrap falls in the steel bath) to speed up the melting with a lower interference with the steel bath stirring;
- keep the connecting car pan inserted inside the EAF for any furnace tilting angle, so as to have the metallic scrap charging and the electrical power-on to the EAF electrodes starting together at the soonest;
- reduce ambient air suction inside the Consteel® and the primary off-gas line by increasing the efficiency of the Consteel® seals between the EAF and the connecting car hood, along the connecting car hood and the conveyor in the preheating section and by better controlling ambient air intake through the dynamic seal;
- maintain high temperatures of the EAF off-gas;
- reduce off-gas flow rate in the primary off-gas line and consequently reducing the electric consumption to the fume treatment plant;
- improve the conditions of the off-gas at the inlet of the heat recovery system (iRecovery®) that will be installed on the primary off-gas line.

The correct conduction of the process is entrusted to a system for supervision and control completely new and innovative, able to interact consistently with management systems of the other production units. This type of system process control belongs to the global solution iSteel®, developed by Tenova for the continuous technological improvement of steel production cycle. The automation of the EAF with Consteel® is complete management system and automatic control of spillage TAT® (Tenova-Auto Tapping-Technology), useful to control the EAF slag flow through the EBT during steel tapping into the ladle and to minimize human intervention during this operation. The design of the new Consteel® system has been updated in order to further improve its reliability and performances, considering the integration of the iRecovery® system. The execution of the project is in progress and the start-up of the new Consteel® is expected by the end of next summer 2015 shutdown.

Enhancements of the heat recovery in Consteel

The melting process in Ori Martin is rather atypical if compared with the other Consteel® EAFs as it employs limited oxygen and carbon injection, this leading to a modest quantity of energy in the off-gases. The main goal of the revamping is to maximize the recovery of the off-gas energy by improving the heat transfer to the scrap in the heating tunnel and by optimizing the conditions of the gases at the tunnel's exit to properly feed the downstream recovery system. The transfer of heat to the scrap will be improved by increasing the scrap exposed surface through the installation of the widest conveyor (2400 mm) compatible with the existing EAF geometry. At the same time the new Consteel® drive will allow increasing the conveying speed by 2 m/min. The changes will result in a reduction of the average scrap height from 800 mm to 500 mm that will boost the average scrap charging temperature at the EAF.
The hoods of the heating tunnel are being completely redesigned applying the results of a CFD analysis ran on the actual off-gases flow data. The aspect ratio of the hoods will be changed as they will become wider and lower, while the overall section will be reduced by about 20%.

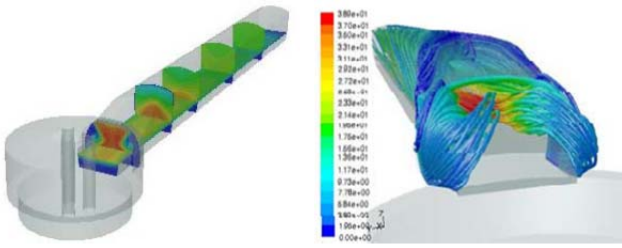

Figure 1. CFD analysis

The efficiency of the energy recovery both in the Consteel® tunnel and in the downstream ECS improves dramatically with the increase of the temperature of the gases. Consistently, the new Consteel® will implement a completely redesigned set of seals to reduce to a minimum the admission of bleed air. The sealing chamber at the open end of the conveyor (the Dynamic Seal) will also be reconfigured to achieve the result: the current seal features an axial fan to reduce the pressure in the seal's chamber and several rows of tubular fingers suspended to the chamber's roof on the scrap's inlet end to reduce the fresh air flow. To improve the dynamics of the chamber pressure control the new configuration utilizes a radial blower whose suction is regulated by pressure probes in the seal's chamber and in the end of the heating tunnel, while the tubular fingers are replaced by newly designed permanent leaf-shaped fingers, built in stainless steel on the hot side of the chamber and in polymers on the cold side. While the pressure in the current chamber is kept slightly higher than the one in the tunnel's end, in the new configuration the chamber will be at a slightly lower pressure, and the outlet of the radial fan will be connected to the secondary EAF suction line.

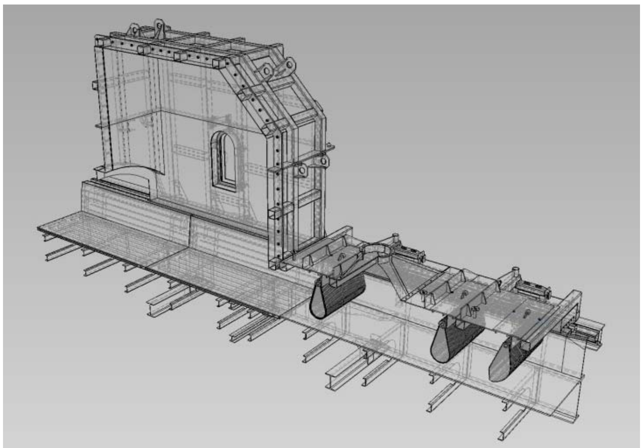

Figure 2. Offtake hood and dynamic seal

To seal the gap between the heating tunnel and the EAF shell a new circular flange, divided in two independent sectors, will be installed. The position of the upper flange will be continuously regulated to adjust the quantity of post-combustion air, controlled through the EFSOP continuous gases analyzer that will assure the complete combustion of CO and H_2 generated into the EAF. Both flange sections will be completely retractable to give the needed clearance for the shell changeover between campaigns.

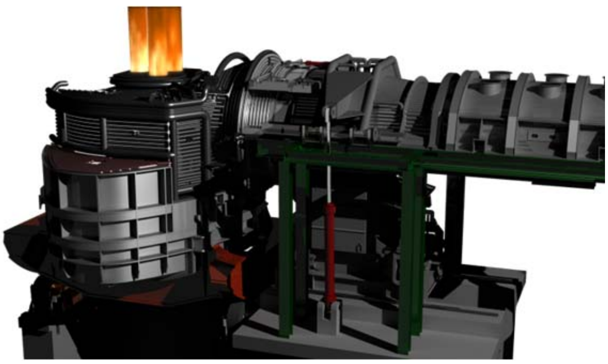

Figure 3. EAF and Consteel connecting car side

The improvement of the seals and the changes in the design of the Dynamic Seal will allow fumes temperatures significantly higher than the ones observed today both inside the tunnel and at the tunnel's exit. To reduce the dust load in the fumes sent to the waste heat boiler and improve the deposition of the metallic dust particles on the scrap layer the offtake hood has also been redesigned, increasing both the horizontal section and the height to reduce the vertical speed of the fumes and increase the residence time of the fumes.

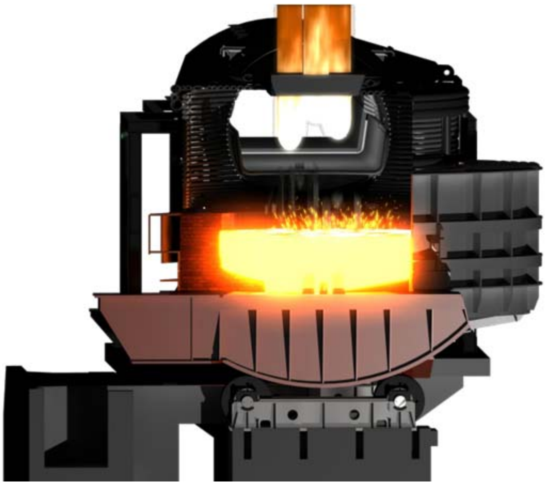

Figure 4. EAF section view

With the existing equipment, the Connecting Car at the end of the conveyor needs to be emptied and extracted from the EAF before tapping to allow free movement of the platform, generating a delay in the admission of the scrap at the begin of each new melt. The EAF platform cradles will be replaced to match the EAF tilting axis and the flange axis, and the Connecting Car will also be improved to allow leaving the connecting car inserted throughout the whole process, eliminating said delay. The design of the new Consteel® will utilize the existing original foundations reducing the shot down time required for the installation of the new equipment.

The iRecovery® concept at Ori Martin

An ECS (Evaporative Cooling System) heat recovery system, iRecovery®, will be installed by the end of 2015 at the Ori Martin steel plant of Brescia. This system, installed downstream of the EAF Consteel® furnace, will have the task to recover part of the energy contained in the fumes generated during the scrap melting and superheating process in the electrical furnace. The energy extracted from the fumes will convert the recirculation water of the cooling circuit into steam. This phenomenon is made possible thanks to the use of cooling water at boiling conditions that, circulating and absorbing energy, will be subject to partial phase change generating steam. During winter time the steam produced will be sent to a heat exchange unit dedicated to district heating for the town of Brescia managed by A2A company. During summer time the steam produced will be used to feed an ORC (Organic Rankine Cycle) turbo-generator for the production of electricity for internal use. This unit will be also used to exploit any excess thermal power remaining after the absorption of heat for district heating. The heat exchanger, generally called waste heat boiler, consists of a single convective exchange unit, operating between fumes temperatures of approx. 500-550°C down to a temperature of approx. 200°C. However, since the EAF process generates heat loads which are not constant over time (scrap melting, liquid steel refining and superheating, tapping, EAF preparation), the fumes temperature has a significant variability over time. In any case, the system is designed to operate within a wide range of temperatures and flow rates. It is essential to consider that the new heat recovery system will have no influence on the steel production process of Ori Martin. It will be installed in parallel to the existing primary off-gas cooling system with water cooled ducts and quenching tower and no unscheduled production stop is required because it has been designed so as to be able to install each part without interfering with the steel production process. The only activities that require a production stop, see connection prearrangements (refractory lined underground tunnel and flange connection to the existing main primary off-gas duct downstream of the quenching tower), will be made during August 2015 planned shutdown. It must be considered that the Ori Martin steel mill in Brescia can operate continuously. The steam generated by the recovery system will be available during this period of production, therefore excluding furnace stops and the periods in which stops are planned for ordinary and extraordinary maintenance. Since the recovered energy will be used by the district heating network of A2A (the electric power and gas distribution company serving the district) and the ORC module, it is assumed that this energy will be fully utilized for such applications. The installation of an additional heat exchange unit is also planned, whose purpose is to dissipate the surplus of energy recovered by the heat recovery system, compared to the energy absorbed by the two users.

System description

The system refers essentially to a heat recuperator that, subtracting the residual thermal energy of off-gas coming out from the EAF Consteel® produces saturated steam which will act as fluid media to transfer the energy recovered to the two main users: the first is the district heating network of A2A, the second is an ORC turbo-generator for the conversion of thermal energy into electrical energy. The recovery of heat and its transfer to the users is carried out according to a continuous cycle where water, coming from the degasser, evaporates into the Waste Heat Boiler, cools down in the heat exchangers of the users and then is sent back in the form of condensate to the degasser, thus closing the thermal cycle. With the aim to optimize the energy recovery process, the system has been designed also considering the possible contribution of energy from a new preheating furnace under commissioning. The system is basically divided into five sections:

- heat recovery section
- heat exchange section with A2A district heating system
- ORC section for converting the recovered thermal energy into electrical energy
- water supply section
- steam pressure accumulation and reduction section

Heat recovery section

The system includes a new off-gas duct, in parallel to the existing off-gas duct to the Quenching Tower, which branching from the refractory lined underground tunnel (upstream of the Quenching Tower), conveys the hot fumes in the heat recuperator, Waste Heat Boiler, and then conveys them to the primary existing off-gas line downstream of the Quenching Tower. On this duct, the following equipment is foreseen:

- a Venturi meter for measuring the off-gas flow rate
- two dampers, one cut-off damper installed upstream of the recuperator and the other for flow rate control installed downstream
- a cut-off damper downstream of the quenching tower in addition to the existing flow rate control one

In case of recovery system blockage or in case of excess of energy recovered, the damper downstream of the recuperator is closed while the damper downstream of the quenching tower is opened so as to completely stop the flow of the off-gas through the recuperator and divert them to the quenching tower. The Waste Heat Boiler consists mainly of a steam generator with natural circulation water tube bundles fitted with:

- casing, namely the fumes flow chamber that contains the convective heat exchange units; it develops horizontally in the fumes flow direction
- evaporators consisting of bundles of vertical tubes crossed by the off-gas inside which the water (liquid phase) coming from the steam drum undergoes a partial evaporation
- steam drum which consists of a cylindrical pressure vessel installed above the recuperator in which the liquid water is in balance with the steam. From the bottom of the steam drum come out both down take pipes that go to the evaporators and the upwards pipes coming from the same evaporators
- economizers consisting of bundles of vertical tubes crossed by the off-gas inside which water is coming from the degasser. In the economizers, water changes from the temperature of about 105°C, to a temperature close to the boiling point, at a defined pressure, in the steam drum; thanks to the economizers the temperature of the off-gas

coming out from the evaporators can be further reduced

- automatic cleaning system of the recuperator that allows the cyclical separation of dust deposited on the surfaces of the exchange units inside the heat machine
- dust extraction system to collect and convey the dust separated in the recuperator up to a storage bin

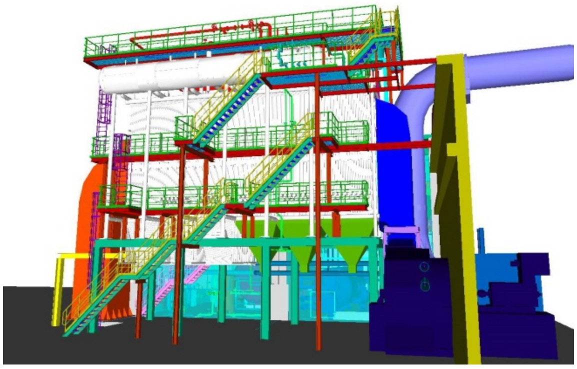

Figure 5. Waste heat boiler

Heat exchange section with A2A district heating

In this section, the steam coming from the steam accumulation section, transfers, by condensing, its energy to the water of the district heating grid of A2A thanks to a heat exchange unit consisting of two condensing heat exchangers operating in parallel, a flash tank inside of which all the condensate is conveyed, and an additional condenser which, in the same way as described in the previous paragraph, condenses back the flash steam bringing it in exchange with the same district heating water. This system not only recovers the re-evaporation heat of condensate that would otherwise be lost into the atmosphere, but it also provides a pre-heating of the district heating water before being sent to the two heat exchangers. All the condensate in the tank is then subsequently sent to the degasser through a booster pump group.

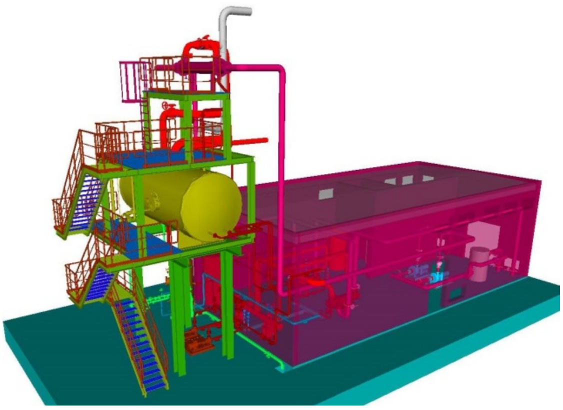

Figure 6: Building with district heating heat exchangers

ORC section

The ORC section consists essentially in a turbo-generator with Organic Rankine Cycle that using the steam from the recovery section converts the recovered heat energy into electrical energy. It consists essentially of:

- centrifugal pump for the circulation of the organic fluid;
- evaporator for the transfer of heat from the steam circuit to the ORC circuit; in this unit the steam, condensing, transfers its energy to the organic fluid which in turn evaporates to be conveyed into the turbine;
- turbo-generator, where the organic fluid under pressure in the steam status transfers its energy producing mechanical work for the conversion into electrical energy;
- condenser that bringing back the organic liquid to the liquid phase restores the initial condition thus closing the Rankine cycle. The organic fluid condensation occurs thanks to the cold water coming from the cooling system existing in the steel mill.

To complete it, Tenova plans to install a unit for the collection and recovery of condensate coming from the OCR evaporator. It consists of an atmospheric tank, called flash tank, within which all the condensate is collected. A part of this condensate re-evaporates after the expansion and is re-condensed in a heat exchanger, called precisely condenser, which uses make-up water to the degasser to cool the condensate. This system not only recovers the re-evaporation heat of condensate that would otherwise be lost into the atmosphere, but it also provides a pre-heating of the make-up water before being sent to the degasser. All the condensate in the tank is then subsequently sent to the degasser through a booster pumps group.

Water supply section

This section is essentially composed of a thermo-physical degasser with turret which carries out a dual role: the first is to ensure continuity of supply to the recuperator in case of non-supply of make-up water; the second is to degas the make-up water, i.e. to allow the elimination of gases dissolved in it.
The degasser is composed of two elements:

- a feed water tank consisting of a horizontal cylindrical tank in which water is stored, this, thanks to the direct injection of steam, is kept at a constant temperature of 105 °C. At the same time the tank collects the condensate from the drainage line and the condensate coming from the users;
- a deaerator that heats the make-up water which is entering in the system at a temperature such as to allow the separation and elimination of the gases present, and in particular carbon dioxide and

oxygen that are the most determining agents for the metallic corrosion phenomenon.

The water in the degasser is drawn from a group of feed pumps and transferred to the steam drum of the recuperator; the pump group is provided with a level control valve that has the task to regulate the flow of water depending on the level of water in the steam drum.

Steam accumulation and pressure reduction section

The steam produced by the recuperator is conveyed to a steam accumulator whose function is to accumulate the thermal energy. In its outlet, on the delivery lines to the users there are some thermal expansion valves whose purpose is to reduce and to ensure the steam pressure at a value below the pre-set value. Furthermore, between the steam drum and the accumulator there is a valve that prevents that the pressure in the steam drum falls below a predetermined value.

The system allows meeting three basic requirements:

- accumulate the recovered thermal energy and release it to the users in the opposite case of no or insufficient energy from the recovery. In this way it is possible to keep the energy transferred to the users at a value roughly constant at around the average value of a complete casting cycle;
- ensure a reduction of the heat load transferred to the users in a smooth manner in accordance with a predetermined ramp in the event of a sudden stop or failure of the recovery system or of the electric furnace that would tend to reduce and stop in a very quick way the heat delivery to the users.
- make as much stable as possible the steam pressure in the steam drum when the thermal load of the fumes varies, which on the contrary is variable and fluctuating in time.

The accumulation of steam exploits the well-known "flash steam" phenomenon: the lowering of the pressure on a liquid mass at the saturation temperature causes boiling and a rapid steam generation to the detriment of its internal energy.

The capacity of the tank to accumulate steam and therefore to store the thermal energy thus depends on the quantity of the liquid contained in it and on the pressure difference that is established between the interior of the tank and the downstream user. It is possible to define two work phases for the steam accumulator:

Accumulator charging phase

Until the steam demand is less than the generated steam, the pressure inside the accumulator increases and consequently also the temperature. The tank is loaded until the entire system does not reach the maximum pressure and temperature design values.

Accumulator discharging phase

If the removal of the steam is greater than that generated, the internal pressure of the accumulator drops. This results in a flash evaporation of the liquid which results in steam available for the users.

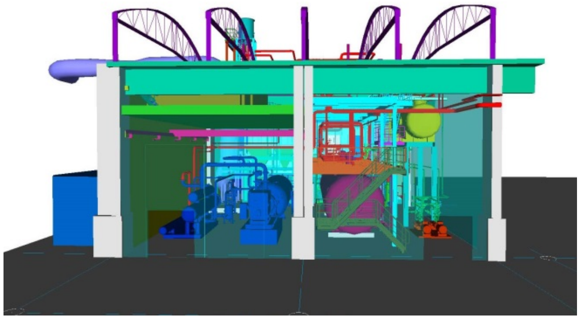

Figure 7: Energy room and ORC room

Auxiliary components

For completion of the system, the following components are foreseen:

- blow-down tank for the collection and safe discharge of the steam circuit drainages that cannot be recovered, this includes also the drainage of the steam drum; it consists of a vertical cylindrical tank where the drainages under pressure are conveyed, depressurized and cooled with cold water and subsequently discharged into the sewer;
- emergency condenser whose function is to cool and then condense any steam in excess in the system in order to prevent unwanted pressure elevations in the system. It is a heat exchanger supplied with cold water, resulting from the cooling system existing in the steel mill;
- de-superheater with water spray for the attemperation of steam coming out from the steam control valve to the emergency condenser;
- silencer for vents under pressure whose function is to reduce at predetermined levels the noise of vents under pressure such as for example those coming from the safety valves in the system;
- steam distribution manifold for sorting the steam coming from the steam accumulator to the different users. The manifold has a collecting sump and a condensate automatic discharge group in order to ensure that the steam at the service of the users is free of moisture;
- corrective chemicals dosage units for feed water

Conclusion

The performances of the new Consteel® will be measured calculating a cost index that will consider energy, electrodes consumptions and other parameters: the reduction of more than 8% of this cost index compared with the current average values is expected. The installation of the iRecovery system, is expected to recover thermal energy from the primary off-gas for a total of approx. 90 kWh/tls that will be available for district heating or ORC turbo-generator.

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