Report

Waste Heat Recovery & Utilization for Steel Plants

Webinar & Workshop Series

10/06/2021

Contents

Introduction

Background

Waste heat recovery and utilization will become and is already a cornerstone for future energy efficient steelmaking, especially since energy efficiency is key to further minimize carbon dioxide emissions and save primary resources.

Within a steel plant there are different waste heat sources available, for example but not limited to:

- Hot off-gases
- Cooling water
- Hot intermediate products like slabs, billets, etc.
- Hot slags

Currently most of these sources are not utilized for waste heat recovery. Besides the technical challenges of the waste heat recovery itself, waste heat utilization (e. g. electric power generation) and market regulations related to this topic have major impact on the feasibility of such projects.

Currently waste heat recovery systems are partially installed at some selected plants (already high TRL), but the majority of plants are not equipped with such solutions. Hence, a comprehensive work is necessary to improve this situation.

The Aims

The three-sessions webinar and one interactive workshop was dedicated to key players dealing with waste heat recovery and utilization in iron and steel industry, such as steel manufacturers, energy supply companies, solutions providers, academics, research institutes, policy makers.

The aims of the webinar and workshop were:

- Overview of waste heat potential (integrated and EAF route)
- Overview of existing waste heat recovery systems in steel plants
- Typical waste heat utilization possibilities as well as global application examples of already applied concepts (district heating, steam generation, electric power production, heat supply to other industries, etc.)
- Advanced options for waste heat recovery (e.g. from intermediate products, etc.) as well as heat storage
- Outlook on current developments & innovative technologies

Webinar & Workshop Committee Structure

The webinars and workshops were organized by a scientific and organizational committee. The members are listed in the following.

Scientific Committee

- Thomas Steinparzer (Primetals Technologies)
- Enzo Chiarullo (Tenova)
- Gerard Griffay (ArcelorMittal)
- Olivier Brégand (CRM)
- Agnieszka Morillon (FEhS)
- Mustapha Bsibsi (Tata Steel)

Organizational Committee

- Thomas Steinparzer (Primetals Technologies)
- Enzo Chiarullo (Tenova)
- Delphine Snaet (ESTEP)

Webinar Sessions

The webinar sessions were consisting of 3 different webinar sessions. The shown presentation material as well as the recordings of the presentations can be found on the restricted area of the ESTEP homepage. The agenda and abstracts of the webinar sessions is given in the following.

Session 1: Waste heat potential and recovery solutions

The topic is focused on the current situation as well as state of the art solutions for waste heat recovery. Contributions on all stages of the supply chain are expected including but not limited to:

- Overview on waste heat potential and opportunities;
- State-of-the art solutions;
- Best practice examples from steel plant operators.

Agenda Session #1

Webinar Session 1 (04.05.21): Waste Heat Potential and Recovery Solutions			
Duration	**Presentation**	**Presenter**	**Session Hosts**
13:00-13:15	Opening words		Gerard Griffay (AM), Mustapha Bsibsi (TATA)
13:15-13:45	Industrial Waste Heat Recovery – An overview on available solutions in modern steel plants	Paul Trunner, Primetals Technologies	
13:45-14:15	Potential of the waste heat recovery in the steel shop	Enzo Chiarullo, Tenova	
14:15-14:45	Industrial District Heating in Linz, Austria	Thomas Keplinger, voestalpine	
14:45-15:15	The future use - Smart heat recovery and utilization in steel site	Tom van der Velde, Tata Steel Europe	
15:15-15:45	Turboden solutions to reach low emission steelmaking	Sabrina Santarossa, Turboden	
15:45-16:15	Different examples of energy recovery systems from Off gas of the EAF of Feralpi Group depending on different opportunities in different sites configurations	Piero Frittella, Feralpi	
16:15-16:30	Closure of the session		

Number of participants: 52 (out of total of 56 registered participants)

Abstracts Session #1

1. Industrial Waste Heat Recovery – An overview on available solutions in modern steel plants

Paul Trunner, Primetals Technologies, Turmstrasse 44, 4031 Linz, Austria

Steel production is a very energy intensive industry. The production of one ton of steel requires large amount of electricity, natural gas, coal and other energy sources. It is well known since decades that a certain part of the energy is going into the off gas and is further emitted to the environment. The utilization of the energy in the off gas attracted more and more attention over the last years.
Waste heat recovery solutions are available on the market for several steel making processes and numerous waste heat recovery plants were built over the last ten years. These plants demonstrate that waste heat recovery is an integral part of today's steel plants.

The development of a waste heat recovery plant requires extensive knowledge as well as long experience of the entire plant, including water-steam cycle as well as EAF process, dedusting system and downstream waste heat consumers. Hence, a deep analysis of the steel making process is the first step of planning a waste heat recovery plant.

Large waste heat amounts can be recovered from Electric Arc Furnace (EAF) and from Basic Oxygen Furnace (BOF). Waste heat recovery plants for these processes must comply with strong fluctuations of the furnaces, making a storage system necessary. Other waste heat sources can be found in at Sinter Coolers or at Reheating furnaces, where waste heat recovery is indispensable in modern steel plants.

A major item for designing a waste heat recovery plant is the utilization of the recovered energy, as it is strongly influencing the economic feasibility of the plant. Thus, this topic arises at a very early stage of the project development. Typical consumer for waste heat recovery plants are district heating, chilled water production, electric power generation or steam generation for various consumers inside and outside the plant.

In this presentation best practice examples for installed waste heat recovery plants along the entire steel making route are demonstrated.

FIGURE 1: WASTE HEAT RECOVERY PLANT IN OPERATION

2. Potential of the waste heat recovery in the steel shop

Enzo Josef Chiarullo[a], Nicola Monti[a], Giuseppe Di Zanni[a]
[a] Tenova S.p.A., Via Gerenzano 58, 21053 Castellanza, Italy

Since more than ten years, TENOVA is involved in the recovery of the waste heat from the industrial furnaces in the steel industry. The Tenova technology, called iRecovery™ system, recovers the waste heat through the steam generation. The flexibility of such energy carrier permits the application of the iRecovery™ system into different steps of the steel production process.
The EAF employs 650-750kWh/tls of chemical and electrical energy, where the scrap melting operations directly uses only 50-55% of the specific energy. The EAF slag, the main by-product of the

EAF scrap melting, uses only 10%-12% of the overall energy input. The EAF process dissipates almost 25-30% of the overall input energy in the waste gases and dust, 10%-12% in the water-cooled EAF panels and other minor losses (i.e. electrical losses, radiation) dissipates the rest of the energy. If continuous charging and scrap preheating, such as Consteel®, is applied to EAF technology, about 5-10% of the overall energy input is directly re-used in the melting scrap process. iRecovery™ system recovers the energy losses in EAF waste gasses by an efficiency 75-80%, corresponding to have the opportunity to re-use up to 136kWh/tls. The present amount of specific energy recovered corresponds about 180kg_{STEAM}/tls produced without any additional fuel burning. Tenova has actually eleven running iRecovery™ system applied to the EAF technology on both scrap basket charging, five references, and continuous charging process, six references.

iRecovery™ system is applicable also downstream to the steel production process in the reheating furnace. Here, the skid system partially dissipates through the cooling water the primary energy supplied, generally, by burners to heating process. Other primary energy portion is lost into the environment by the heat contained in the waste gases, after the recuperator for air combustion preheating. In the reheating process, depending on the fuel and the technology used, the specific energy input is about 400-650kWh/ton, where steel preheating process directly absorbs only about 55% of the primary energy, but 5-9% and 12.5-18% is actually dissipated in the skid system and waste gas after recuperator respectively. iRecovery™ system recovers up to 90kWh/tls, which corresponds to 118kg_{STEAM}/ton producible without additional fuel burning. Tenova has two recent references in operations of iRecovery™ system applied to the reheating furnace.

The applications of the iRecovery™ technology leads to a potential savings of about 226kWh/tls, which are equivalent to 22,7Nm^3/tls of natural gas with the consequent avoidance of CO_2 emission. Power generation needs also saturated steam: iRecovery™ leads to a production up to 41kWhe/tls without any additional GHG emission.

3. Industrial district heating in Linz, Austria

Thomas Keplinger, voestalpine

The voestalpine group's steel division is located in the suburban area of Upper Austria's capital Linz. voestalpine operates an integrated steel plant with three blast furnaces, BOF steel plant and a number of rolling and coating facilities with focus on high quality steel grades for our customers. The customer segments are automotive, electrical, house, processing and machinery industry as well as the energy sector. Our primary decarbonization strategy is Carbon Direct Avoidance, but to achieve our ambitious goals in a short term, enhancing the energy efficiency is the most valuable way to reduce energy consumption. As the voestalpine is located in the suburban area of Linz, providing the city with hot water for the district heating net is obvious. Therefore, voestalpine is harvesting waste heat from the basic oxygen furnace gas cooling and the reheating furnaces off-gases in the form of saturated and superheated steam. In a second step, the steam is condensed and subcooled to heat up the district heating water to the required temperature for the net. From a technical point of view, decoupling hot water is not difficult. However, there are always obstacles when voestalpine thinks towards enlargement of the connection pipes capacity, which would easily be possible regarding sufficient waste heat streams. The issues arose mostly from an economic and managerial point of view. Other industries displace industrial waste heat based on highly promoted primary energy sources or on natural gas combustion. voestalpine would appreciate it a lot, if already existing and unused sources of waste heat get priority and an easier market access. Therefore, voestalpine would like to contribute to the webinar and to discuss with other plant operators their issues concerning waste heat recovery e.g. use of hot water in summer.

4. The future use - Smart heat recovery and utilization in steel site

Tom van der Velde, Tata Steel Europe

The iron- and steel-industry is the second most energy intensive industry in the world (IEA, 2015[b]), small increases in energy efficiency have relatively large impacts on global carbon emission. If we zoom in on Tata Steel the Netherlands, it accounts for 7% for the national CO_2 emissions.

An important mechanism to save energy and CO2 emissions is Waste Heat Recovery (WHR). This is due to high temperatures needed in the steel process that could be reused in the same or another process. The waste heat comes in the form of flue gases, cooling water or the main- or by-product

The research at Tata Steel conducted on WHR is to determine the different Waste Heat sources for the whole site. To determine the feasibility of the applications, the analysis is based on three different perspectives:

- Technical perspective: Does the application utilize waste heat steel plant source?
- Environmental perspective: Does the application decrease of CO_2 emissions?
- Economic perspective: Does the application provide a viable business case?

The research utilizes a technical, environmental and economic perspective to assess feasibility of waste heat applications. Case studies are performed, where a large number of waste heat sources are identified. Application scenarios are derived for these sources and consist of a utilization technology. The technologies perform the necessary cleaning, heat storing, heat upgrading or heat transporting depending on the requirements of the utilization technologies and the characteristics of the waste heat sources. The application scenarios vary from: Heat to Power, Flexibility concepts (Thermal Energy Storage) district heating networks (DHN) carbon capture units

For the environmental analysis, the application scenarios are assessed based on energy reuse efficiency and reduced CO_2 emissions.

Feasible energy savings potentials are between 0.3 PJ and 2.7 PJ per year. Feasible carbon emission reduction potentials are between 25 ktonne and 140 ktonne per year. For the economic analysis the Payback periods (PBP) are calculated for all application scenarios.

The WHR sources that are most feasible to utilize have the highest temperatures. Subsequently, the application scenarios with the lowest temperature requirements, have the highest feasibility, even if heat storage or and transporting infrastructure is necessary.

Most scenarios all looked at the direct use of the waste heat streams, but recent technological improvements have created ways to not only recover waste heat but even store it. This is called Thermal Energy Storage (TES). By being able to store the waste heat and use it later, less fossil fuels have to be used. Another improvement from TES in an industrial setting is the creation of more flexibility in the heat delivery options.

By providing Tata Steel the Netherlands with solutions for WHR utilization, energy savings and GHG reduction can be achieved. This is beneficial for the ability of the Netherlands to comply with national climate change agreements. Furthermore, the applications themselves can influence national and local society. If the WHR could be reused in district heating networks, heat will be supplied to the households or companies in the vicinity of TSIJ. This would have large impacts on current heat infrastructure. It could also create more awareness on the topics of energy consumption and climate change.

5. Turboden solutions to reach low emission steelmaking

Sabrina Santarossa, Turboden

Nowadays, all major steel groups are at work with technology partners to define and implement the steps necessary to convert their iron ore and coal-based primary production facilities in Europe in order to drastically reduce emissions and be able to reach the 2050 European Union climate targets.
Among the different paths pursued within the steel community, the Electric Furnace route coupled with upstream gas based direct reduction and the next introduction of green hydrogen appear to be the most promising option to replace Blast Furnaces and eventually achieve fossil free steelmaking in Europe.
In additions to these major strategic tasks, steelmakers must also continuously upgrade their facilities with smaller incremental steps to improve the energy efficiency and sustainability of their operation and to stay competitive.
In this framework, Turboden offers several solutions to the steel making plants in their way to sustainability. The most known Turboden technology is the Organic Rankine Cycle (ORC) one, installed in several waste heat recovery steel plants since 2013. In the last years other technologies have been developed by Turboden such as Large Heat Pumps (LHP) and Gas Expander (EXP).

Recovery and full utilization of waste heat in energy-intensive steel process is primary to save energy and lower emissions.
In several instances, waste heat recovery systems have proven to be an effective way to put to good use the steelmaking hot exhaust gas energy, producing hot water for space heating or saturated steam for steel processing (e.g. pickling). The heat recovered replaces fossil fuels previously used, reducing Scope 1 emissions.
When heat users are not sufficient, the residual energy available is still valuable after converting heat to power in a Rankine cycle. This allows reducing Scope 2 emissions.
Today, EAF energy efficiency systems, recovering off gas heat and converting it to mechanical/electric energy, have become a well-proven practice in several mini mills in Europe thanks to ORC technology. In fact, ORC systems have become, in the last 30 years, the preferred choice firstly in renewables, such as biomass, and secondly in small-to-medium size heat recovery systems, because ORCs offer energy savings and guarantee continuous safe & automatic operation with no need of dedicated personnel.

Beside hot exhaust gas, in a steel production facilities hot water is available. In several cases, there are heat users close to the steel industry, who ask for large amounts of thermal energy, at a higher temperature compared with the residuals water cooling present in the steel plant. In this framework, heat pump technology can valorize such low-grade residual heat – otherwise wasted - that can be boosted to the heat user demand. These heat users could be either directly part of the steel making production process or indirectly neighbour industries or district heating networks, thus enhancing synergies between industries.
Turboden, taking advantage of its long-lasting experience with high temperatures, developed a heat pump technology which is not limited to the traditional low-temperature heat outputs (<90°C), but can reach higher enthalpies with the possibility to heat different heat carriers up, including steam generation. This innovative feature allows to apply the technology to a wider range of applications.

Another potential form of energy is available at the natural gas (NG) delivery points of industrial facilities: this is the case of NG pressure reduction process. Industrial facility letdown stations are meant to reduce high-pressure NG to a medium-low pressure level. The traditional system utilizes throttling valves that dissipate the energy contained in the pressurized NG to reduce the pressure. This kind of functioning, albeit effective, is not efficient since it inherently wastes energy that could be recovered. EXP can valorise that process and become a valuable alternative and a more efficient solution. The basic concept of an EXP is to exploit the energy that otherwise would be lost through throttling valves: the pressure drop becomes the "driving force" to produce electric power. Similar to ORC, it consists in a turbine through which the NG at high pressure, rather than being reduced with valve, expands to produce work, thereafter converted into electricity by a generator. Moreover, EXP can utilize processes waste stream for the NG preheating process rather than the traditional gas boilers, therefore increasing the efficiency and the sustainability of the process.

As we have seen Turboden offers high performing and easy-integrated solutions to increase the sustainability of steel making process, contributing to the decarbonisation of industrial processes, while at the same time enhancing their efficiency. On this regard, the electricity produced by ORC or EXP can also be combined with electrolyzer to locally produce green hydrogen and to support the energy transition for a cleaner and more sustainable planet.

6. Different examples of energy recovery systems from Off gas of the EAF of Feralpi Group depending on different opportunities in different sites configurations

Piero Fritella, Feralpi

For industries with energy intensive use the increase of energy efficiency is a relevant target to obtain both scopes of cost production and environmental footprint reduction.

In particular the steel production by electrical route is characterized by intensive enrgy use, both electrical and chemical energy, in the electrical arc Furnace (EAF) for scrap melting and relevant emissions of CO_2 to the atmosphere.

During the EAF process about 15-30 % of energy in input is lost with off gas and opportunities of energy recovery from it is taken into account in this summary in generation of steam and electricity for different uses also considering different plant configurations.

The energy in exit by the EAF through the Off Gas is characterized by high power resulting in an high gas flow rate (100.000/200.000 Nmc/h) at high temperature (900/1400 °C) and with high content of dust and not combusted compounds.

The application of energy recovery from the EAF off gas is not frequent due to aggressive conditions of the flow characterized by high temperature, presence of not combusted species and dust with different size. These conditions request the off gas treatment to reduce dust emissions dioxin formation and to avoid high temperatures and arrival of not combusted particles to filters.

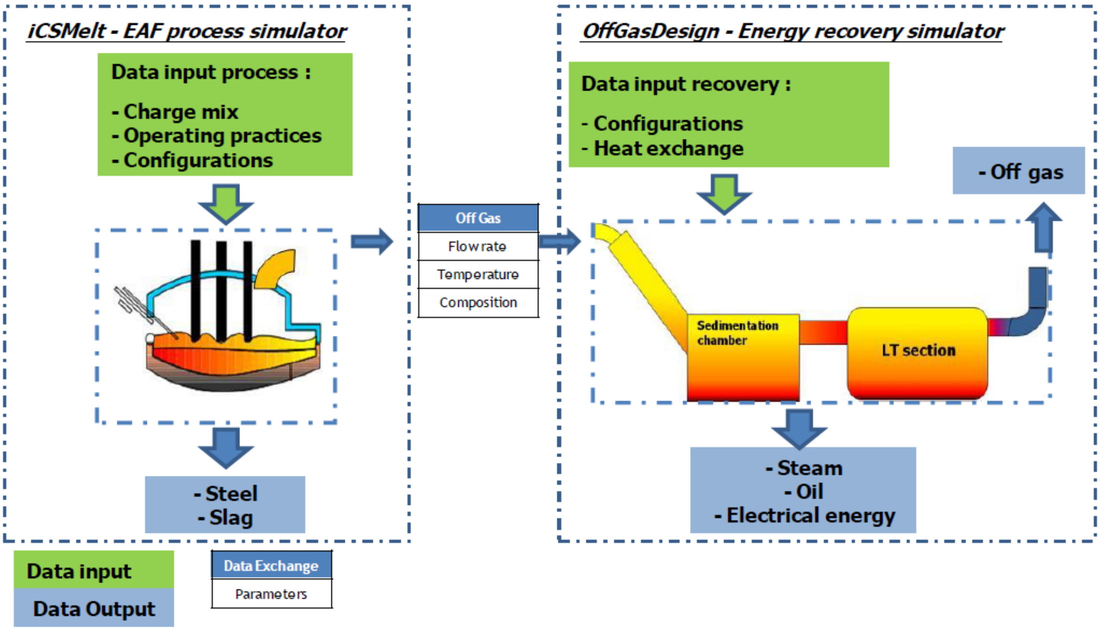
Feralpi has followed as first the application of systems to recover the energy from the off gas of EAF also producing electrical energy. In particular, since 2013 the installation of an energy recovery system to the EAF plant of Elbe Stahlwerke Feralpi Gmbh (ESF) has been coupled to obtain generation of steam and electrical energy by the wasted heat in off gas.

This installation based on evaporating cooling system (ECS) of Tenova (iRecovery) and the ORC technology (Organic Rankine Cycle) of Turboden.

After this experience, the energy recovery system has also been applied in the Italian site of Feralpi Siderurgica in Lonato del Garda.

Due to the different configuration of the EAF site of Feralpi Siderurgica a different approach has been followed devoted mainly to recovery energy with hot water for different uses as internal district heating, internal district cooling , district heating to the external surrounding community of Lonato del Garda.

The two different applications are here described.



Session 2: Waste heat recovery solutions and advanced options

The topic mainly concerns advanced waste heat recovery solutions which are already on an industrial prototype level.

Agenda Session #2

Webinar Session 2 (11.05.21): Waste Heat Recovery Solutions & Advanced Options			
Duration	**Presentation**	**Presenter**	**Session Hosts**
13:00-13:15	Opening words		Thomas Steinparzer (Primetals Technologies), Enzo Chiarullo (TENOVA)
13:15-13:45	Scaling-up advanced waste heat recovery solutions, from laboratory to industrial plants	Olivier Bregand, CRM	
13:45-14:15	Heat Recovery of Sinter Circular Cooler by an Integrated Dedusting and Heat Recovery System	Rongshan Lin, Dillinger	
14:15-14:45	Heat pipe assisted annealing for energy saving in continuous annealing	Metin Celik, Tata Steel Europe	
14:45-15:15	ECOSLAG – Heat Recovery for Operational Practice	David Algermissen, FEhS & Virpi Leinonen, SFTEC	
15:15-15:45	ECOSTOCK®: High Temperature Energy Storage Solution	Gaétan Mandagot, ECOTECH	
15:45-16:00	Closure of the session		

Number of participants: 48

Abstracts Session #2

1. **Scaling-up advanced waste heat recovery solutions, from laboratory to industrial plants**
   Jean Borlée, Frédéric Van Loo and Olivier Brégand – CRM Group

The presentation focuses on a few breakthrough WHR solutions developed at CRM Group in recent years. The transposition of early laboratory developments to industrial scale and their fit with real life production and daily challenges is examined.

Waste gas and waste heat recycling at the sinter plant is studied and tested at CRM since more than 20 years. This generic environmental solution is increasingly deploying in industrial plants.

CRM Group is notably equipped with dedicated numerical tools and testing facilities to identify the best suited process configuration, considering plant lay-out, technical objectives, as well as operational and economical constraints of the plant.

Another recent heat recovery development also presented aims at recovering low-temperature heat of waste gas and fumes.

2. Heat Recovery of Sinter Circular Cooler by an Integrated Dedusting and Heat Recovery System

Rongshan Lin; Andreas Feiterna; Guido Maurer; Jean-Paul Simoes, Dillinger

After discharging from the sintering strand, sinter product has still a temperature of around 800°C. The hot sinter must be cooled before being transported to blast furnaces. It takes place usually in a circular cooler where the ambient air is blown through the sinter bed. Thereby dust emissions arise and exhaust heat is released in large part to the ambience. In order to reduce the dust emission and to recover the sensible heat of the hot sinter, ROGESA (Roheisengesellschaft Saar mbH), a joint subsidiary of Dillinger and Saarstahl, had decided to build an integrated dedusting and heat recovery system at No. 3 sinter machine. As a consequence, comprehensive investigations and trials were carried out by varying different operational parameters in order to find out the optimal set point and design.

A large area on the circular cooler is covered by a hood. In this way, dust emissions generated are extracted together with the hot exhaust air in a controlled manner and fed to a filtering system after passing an integrated heat extraction system. The heat from the exhaust air is transferred to a hot water circuit which is connected to the BF top gas power plant to preheat its feed water. The heat recovery generates an additional energy benefit of 82,000 MWh, which equals a reduction of carbon emissions of approx. 25,000 tons per year. The separated dust particles from the filter system are returned to the production cycle and recycled in the sinter plant.

3. Heat pipe assisted annealing for energy saving in continuous annealing

Metin Celik, Tata Steel Europe

An alternative technology for the continuous annealing of steel is invented at Tata Steel IJmuiden R&D and further developed in collaboration with Drever International and TU Delft. This technology is called heat pipe assisted annealing (HPAA). The aim of HPAA is to provide a more energy efficient way of annealing packaging steel. HPAA concept is based on recovering some of the heat removed during the cooling stage of annealing and using it in the heating stage. This heat exchange is achieved by thermally linking the cooling strip to the heating strip with multiple rotating heat pipes. Only final heating and cooling of the steel strip is carried out in a conventional way. The detailed simulations performed for a typical HPAA line with a steel strip of 0.25 mm, a line speed of ~6 m/s and an average wrap angle of 104° shows that an energy recovery of ~70% can be achieved with 60 heat pipes. It is also observed that the thermal cycle requirements can be satisfied with this new technology.

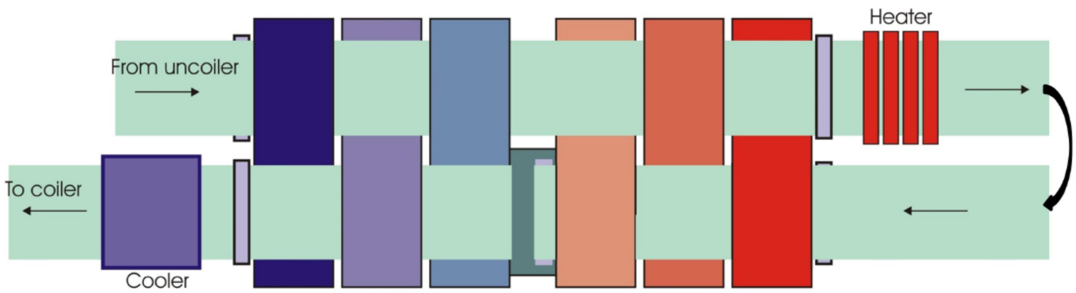


FIGURE 2. HEAT PIPE ASSISTED ANNEALING CONCEPTUAL REPRESENTATION.

4. ECOSLAG – Heat Recovery for Operational Practice

Algermissen, David; Morillon, Agnieszka [1], Leinonen, Virpi [2]
[1] *FEhS – Building Materials Institute, Bliersheimer Str. 62, 47229 Duisburg, Germany*
[2] *SFTec Oy, Paavo Havaksen tie 5D, 90570 Oulu, Finland*

In recent years, finding solutions to recover heat from different slags was an important topic. Several techniques already exist to recover most of the heat from iron & steel slags, but these techniques did not find their way into operational practise due to different reasons, e. g. the system is very complex or the slag quality/marketability decreased.

The ECOSLAG project aim is to find practical solutions to recover heat from slags while keeping the slag quality high and therefor its marketability, as well as to develop non-sensitive processes with low maintenance. Different solutions are proposed in ECOSLAG project depending on the specifications and needs of different steelworks.

One part in this RFCS funded project is the direct use of heat from ladle furnace slag (LFS) in the EAF. Due to the specific crane railways' layout and the logistics inside the steelwork, often it is not possible to transport liquid LFS to the EAF. Other solutions have been investigated to fine-tune the transport of the hot LFS without disintegration to use the heat directly in the EAF as well as to substitute natural slag formers.

Another part of the project has concentrated on development of a heat recovery device called RecHeat, for direct heat recovery from hot liquid slag. The RecHeat is a patented heat exchanger type of structure on which the liquid slag is poured and air is used as a media to recover the heat from the slag, without need for water. New design of the RecHeat was tested with the BOF slag in semi-industrial scale during the ECOSLAG project. The heat recovery efficiency of RecHeat showed its potential for practical use, where one heat of slag provided air with temperature over 80 °C for several hours which can be used for drying (e.g. ModHeat®).

5. ECOSTOCK®: High temperature energy storage solution

Guilhem Dejean, Gaétan Mandagot, ECOTECH

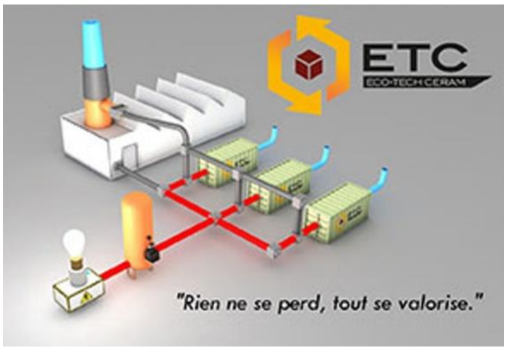
Eco-Tech Ceram (ETC) is an ecological engineering company which provides energy recovery solutions from wasted heat related to industrial processes in order to improve the energy efficiency and the profitability. ETC provide sustainable and cost-effective turnkey solutions for waste heat recovery and storage. The start-up EcoTech Ceram, a product of French research, is offering a new way of storing energy for industrial companies. The aim is to recover, store and use energy in a profitable and sustainable way.

Eco-Stock® is a rechargeable heat accumulator which can stores the waste heat from 300°C. It has been awarded by ArcelorMittal for "Prix des Innovateurs".

Eco-Stock is a heat rechargeable battery that can withstand temperatures of up to 1000°C. In concrete terms, it consists of a thermally insulated container in which ceramic bricks are placed. The composition of these bricks, whose manufacture is subcontracted by Eco-Tech Ceram, is protected by a patent and use recycled materials.

The hot air released by the industries is diffused into the ceramic bricks (charge cycle). It can thus be stored for several days with however 5% of thermal losses per day. Its storage capacity varies between 1 and 3 MWh. The heat is then restored (discharge cycle):

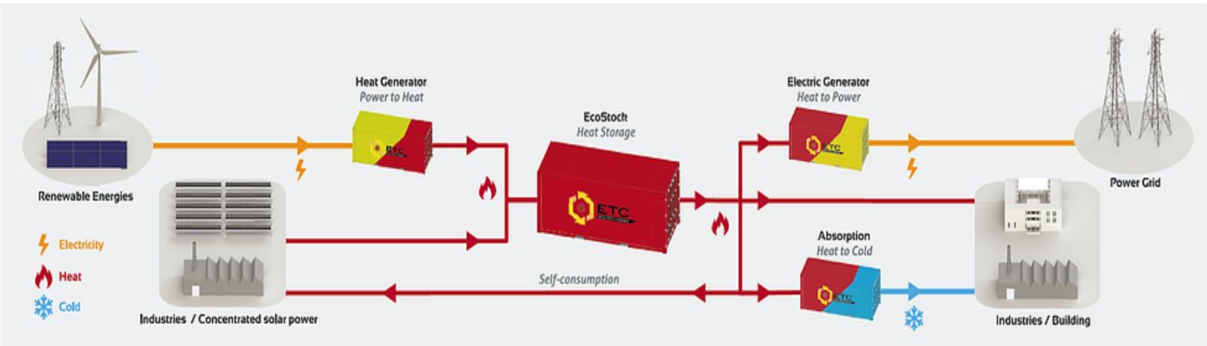
- either directly in the form of heat (heating of buildings, preheating of a furnace...)
- or in the form of industrial cold
- or in the form of electricity



In addition, it is possible to put "batteries" in parallel in order to optimize the charge/discharge cycles: when one of the EcoStocks is charging, the other one is discharging. This is particularly useful for industries that produce heat continuously. Thanks to a modular "Plug and Play" system, the heat can be used directly on site or transported to another site by truck, train or boat.

Eco-Tech Ceram has three main interests in using its heat stack:

- An economic advantage: for a small and low-risk investment (there is no need to modify existing infrastructures), it is possible to obtain energy that is 80% less expensive than natural gas for example.
- A technical advantage, since the stored heat can be used at any time at constant temperature and power. Indeed, the Eco-Stock is a thermocline system that combines an optimized geometry, sensors (temperature, flow) and an energy management system to produce customized heat.
- An environmental advantage: in addition to energy savings, the Eco-Stock uses materials from the Circular Economy (the famous ceramics).



Session 3: Outlook on future developments

An outlook on latest developments in waste heat recovery with a special focus on thermoelectric generators as well as a comprehensive view considering future transitions in iron and steel industry (enhanced EAF scrap route) and integration of waste heat into external networks (e.g. sector coupling) is given.

Agenda Session #3

Webinar Session 3 (18.05.21): Outlook & Future Developments			
Duration	**Presentation**	**Presenter**	**Session Hosts**
13:00-13:15	Opening words	Morillon / Bregand	Agnieszka Morillon (FEhS), Olivier Bregand (CRM)
13:15-13:45	Research paths for waste heat recovery: the contribution of ESTEP roadmap for an improved EAF scrap route	Ismael Matino, SSSA (TENOVA, ESTEP)	
13:45-14:15	Integration of industrial excess energy in external networks from a legal-economic perspective	Simon Moser, Energieinstitut JKU	
14:15-14:45	Waste heat thermoelectric exploitation in steelmaking: a critical review	Marco Bianchi, Acc. Venete	
14:45-15:15	HEAT-R ENV: Improving the energy efficiency of steel industries using waste heat recovery units based on thermoelectric modules.	Raul Aragones, AEInnova	
15:15-15:45	INDUEYE-2.0: Making the steel industry more digital, sustainable and efficient using new long-range wireless edge-computing IoT devices fully powered by waste heat.	Raul Aragones, AEInnova	
15:45-16:15	Radiant Heat Capturing Device for Steel Mills	Saioa Herrero, Tekniker	
16:15-16:30	Closure of the session	Morillon / Bregand	

Number of participants: 45

Abstracts Session #3

1. Research paths for waste heat recovery: the contribution of ESTEP roadmap for an improved EAF scrap route

Ismael Matino[a], Valentina Colla[a], Enrico Malfa[b], Marta Guzzon[b], Enzo Josef Chiarullo[b], Klaus Peters[c]
[a] Scuola Superiore Sant'Anna, TeCIP Institute – ICT-COISP, Via Moruzzi 1, 56124, Pisa, Italy
[b] Tenova S.p.A., Via Gerenzano 58, 21053 Castellanza, Italy
[c] European Steel Technology Platform (ESTEP), Avenue de Cortenbergh, 172, B-1000 Bruxelles, Belgium

The ESTEP roadmap for an improved EAF scrap route provides the following vision: *the EAF-based steelmaking route of the future is a sustainable seamless production chain, integrated in the society in terms of optimal use of raw materials and resources, including energy and its flow, contributing to welfare and progress of the surrounding communities and of the society as a whole*. The aim of this roadmap is to provide paths to be followed to reach the EAF-based steelmaking route of the future.
Considering that 50% of energy input in EAF melting process is dissipated in the environment, energy recovery and utilization is a priority topic of the roadmap, which globally includes six intervention areas: primary raw material and rational utilization of the energy in EAF-based route, the alternative and environmental-friendly energy sources, the resource efficiency improvement and the implementation of new tools and sensors.

Main sources of energy losses in EAF production chain are off-gases, slags, and cooling water. Potentials are huge, but the main barrier for the application of the energy recovery technologies to the EAF are the high CAPEX compared to the standard pay-back period of 3 years in the steel industry. Consequently, future R&D&I activities should be focused on increasing efficiency and value of recovered heat while decreasing investment costs. This overall goal refers to all the key aspects and research lines (strictly linked to the waste heat sources) that must be followed to reach about 30-35% and 8-10% of EAF energy input recovery, respectively, from waste gas and from other media. Several actions are proposed for the different research lines and considering short, medium and long times in a time horizon of 10 years. For instance, the exploration of new energy carriers such as molten salts or technologies for recovering heat from lowest off-gas temperatures as well as for power and green hydrogen generation are envisioned for improving energy recovery from off-gas. These two last solutions are in line also with recovery of low grade heat from cooling water, as the possibility of power generation at low temperature by Peltier cells using the hot-water. Furthermore, the hydrogen production by using SOEC technology can take advantage from the steam generated by recovered heat by high temperature gas. In addition, dry slag granulation is close to reach a suitable readiness level to recover heat from slag, but new challenges could concern the exploitation of radiation by slags and hot slabs for electrical energy generation.
Besides the plan for the application of proposed actions, expected impacts, Technology Readiness Levels evolution, risks and solutions are also proposed in the roadmap.

2. Integration of industrial excess energy in external networks from a legal-economic perspective

Simon Moser (presenter), Marie Holzleitner, Energieinstitut an der Johannes Kepler Universität Linz

In a sustainable energy system, energy efficiency is an essential component. This results in the objective of utilizing a company's excess energy externally when there is no internal usage.

The feed-in of electricity has positive and negative characteristics: On the one hand, feeding into the grid is simple as technical parameters are precisely specified, expected revenues are clearly visible through transparent market prices, and there are enough buyers on the transcontinental market. On the other hand, there are legal guidelines and market design requirements, such as schedule compliance and control energy costs.

The integration of industrial waste heat into external district heating networks or the use in the course of a B2B energy cooperation is more complex. The trade takes place between two highly individual partners and not on a transparent market. There are no standardized technical specifications and information is “private”, i.e. one partner must trust the other one. The allowance to enter the heat market is not legally binding.

However, it is shown that optimal results can be achieved under the premise of joint economic efficiency; thus, regulation of the feed-in e.g. feed-in obligation for industries or acceptance obligation for district heating operators, is not recommended. However, it is essential to motivate partners to exchange information and seek consensus. Therefore, the second alternative listed in the RED II, which means that district heating network operators must increasingly integrate renewable or waste heat, seem appropriate to enforce industrial excess heat utilization.

3. Waste heat thermoelectric exploitation in steelmaking: a critical review

Marco Bianchi, Riccardo Ottini, Acciaierie Venete

Among several industrial waste heat recovery ways, we decided to focus onto the recovery by directly convert thermal energy into electric power. Thermoelectric generators have the advantage to avoid demanding industrial installation and can be easily installed also in hard reachable location such as preexisting continuous casting machines or where is difficult to install available waste heat recovery solution and so on. Nowadays, the principal drawback is the relatively low electrical efficiency of the available devices. Nevertheless, we think is far better to be able to use even a small source of energy rather than waste it. Moreover, to store and readily reuse the energy obtained via thermoelectric generation (a direct electric current) it is imaginable to use it to electrolyse water getting O2 and H2 that could be used for other steelmaking processes (EAF and RHF).

Several papers describe experiments in steel plants where thermoelectric modules are put in radiant exposure of hot surfaces. Varying radiant surfaces and cooling rate can improve or reduce the power generated. This work reviews the principal research items to lay the groundwork for the extensive future development of thermoelectric generators in our company in particular and in steel industry in general.

4. HEAT-R ENV: Improving the energy efficiency of steel industries using waste heat recovery units based on thermoelectric modules

Raul Aragones, AEInnova

Europe energy-intensive industries lose 700TWh of energy every year due to energy inefficiency, in the form of waste heat emissions. This value corresponds to 21% of the energy needs of Europe per year.

One possibility to improve their energy efficiency consists of converting this heat into electricity using energy harvesting technologies.

AEInnova proposes an adaptable and integrated solution for steel industries seeking to increase their energy efficiency and minimize their carbon footprint. The direct conversion of WH into electricity is based on a thermoelectric principle called the Seebeck effect. The novelty over current technologies is how we interconnect them electrically to obtain the maximum energy harvesting performance and how they are controlled through an international patent technology, overcoming actual limitations.

This technology has been granted by the European Commission LIFE16 Programme ENV/ES/000344 Heat-R Project (link to project) developing several pilots in Cement, Paper and Chemical and in the 2021 Summer in the Steel sector in CELSA Group, achieving a total potential power generation of 600Wp / m^2 at 350ºC.

5. INDUEYE – 2.0: Making the steel industry more digital, sustainable and efficient using new long-range wireless edge-computing IoT devices fully powered by waste heat

Raul Aragones, AEInnova

This abstract presents INDU-EYE, a novel long-range wireless and battery-less industrial Internet of Things device (IIoT) powered by waste heat for measuring and predicting machinery vibrations. These self-powered devices will help iron & steel & aluminium industries to become more environmentally friendly and profitable in their digitalization transition towards Industry 4.0. Moreover, due to the lack of batteries, new long-range wireless protocols may be adopted such as NB-IoT or LoRAWAN, eliminating all the wireless infrastructure in the facility. Additionally, the edge-computing concept is introduced in this device reducing up to 98% the cloud computation.

This technology has been granted by the European Commission H2020 EIC Pilot INDUEYE 2.0 (link to project) developing several pilots that now are certified and commercial products installed in energy demanding industries such as TUBACEX (Stainless steel tubing suppliers), Ferrovial (Biogas), Sacyr Valoriza (Rubber), REPSOL (oil&gas), etc. Moreover, this technology as been awarded by the Energy Transition AWARDS (DENA), the Industrial Internet Consortium (best innovative technology), the UN ODS7, among others.

Data monitored are represented in DAEVIS, a cloud-based IoT dashboard with predictive maintenance capabilities.

6. Radiant Heat Capturing Device for Steel Mills

Saioa Herrero López[1], Susana López Pérez[1], Jon Iturralde Iñarga[2], Mercedes Gómez De Arteche Botas[2]
[1]TEKNIKER, Eibar (Gipuzkoa), Spain
[2]FUNDACIÓN TECNALIA RESEARCH AND INNOVATION, Azpeitia, (Gipuzkoa), Spain

Although the capture of industrial waste heat has increased in steelmaking, the energy sources are typically limited to exhaust gases, using convection as a mechanism for recovering their waste heat. However, in the steelmaking process there are intermediate products at high temperatures, which constitute a significant source of radiant energy that remains unexploited as a source of waste heat.

With the aim of seeking a way to exploit this residual heat, a device has been developed for the recovery of radiant heat from continuous casting and other steelmaking processes. This device has been conceived to obtain heat of the highest possible temperature (300-400ºC), thus expanding the range of uses inside and outside the plant. The device has been designed with the criteria of maximizing both the heat that reaches it (optical properties) and the heat that is subsequently absorbed by the corresponding heat transfer fluid. The design has also considered the minimization of heat and pressure losses, cost, and the assurance of the device's integrability in the process.

After going through the different phases of the design, the work continued with the construction of a prototype and an ad-hoc test bench to test it. The test bench includes a thermal loop that feeds the device and a radiating element that emulates an incandescent billet. The results obtained from the tests confirmed the values expected from simulations, resulting in considerably high heat recovery efficiency. Next steps would include the implementation and testing of a new and improved prototype in a real environment.

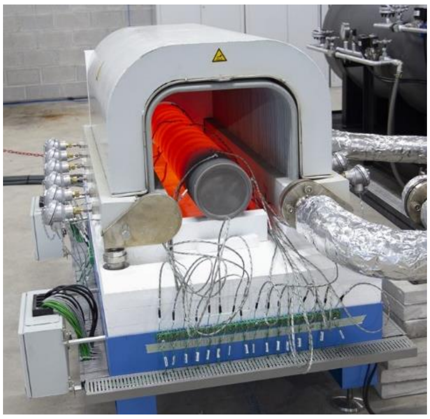


Figure 3. Prototype of the radiant heat capture device

Figure 4. Testing of the radiant heat capture device prototype at the test site

Workshop

Session 4: Interactive Workshop

The final session will be an interactive workshop, in which the missing factors for a wide application of waste heat recovery systems in iron & steel industry shall be identified in small working groups for individual techno-economic topics. The missing factors identified in the small working groups will be afterwards collected as well as jointly evaluated and shall be basis for future roadmaps. Target of the workshop is to identify the white spots for a wide application and elaborate a basis for future roadmaps. The techno-economic topics for the working groups can be selected during registration.

Workshop Agenda

Session 4: Workshop		
Time	**Agenda**	**Moderator**
13:00-13:05	Welcome & Dial-in	Steinparzer
13:05-13:25	Framing / Explanation of workshop concept, target, technical procedure	Steinparzer
13:25-13:30	Division into breakout rooms / topics	Snaet
13:30-14:30	Discussion / elaboration in each breakout rooms / topics	Participants
14:30-14:45	Break	Participants
14:45-15:45	Presentation and joint evaluation of breakout rooms / topics results	Moderators Break-out rooms / Steinparzer
15:45-16:00	Wrap-up & Summary	Steinparzer

Number of participants: 28

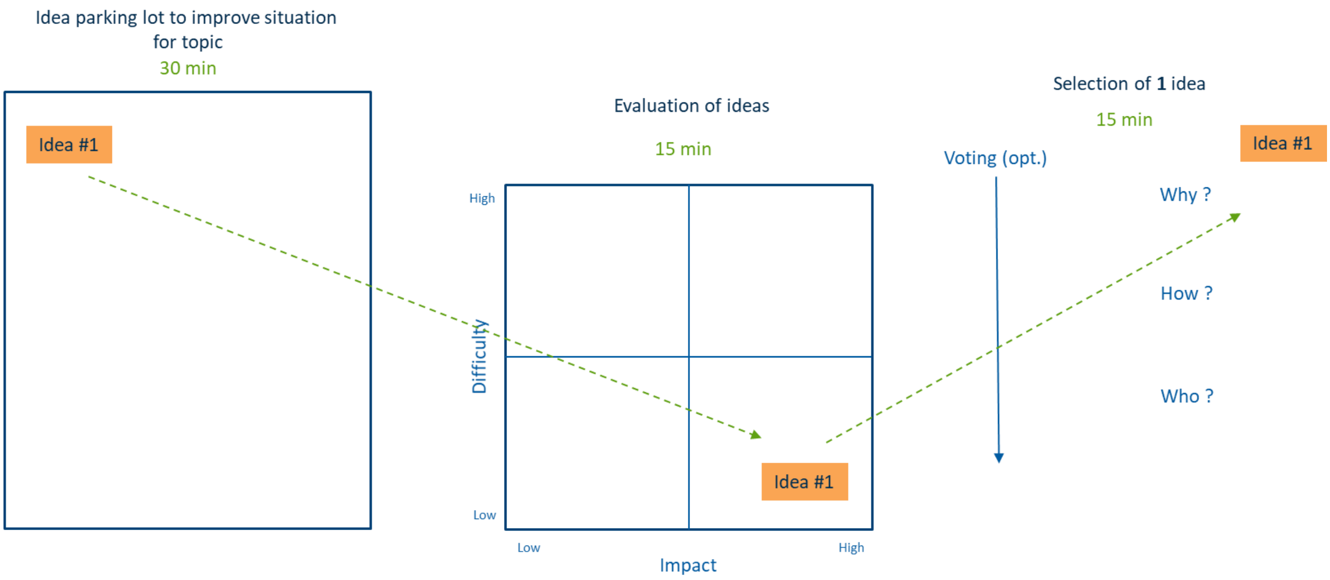
Workshop Concept

The targets of the workshop were to identify missing factors resp. problems for limited applications for waste heat recovery systems and to collect ideas to overcome the current situation.

To facilitate the achievement of the mentioned target above the workshop was split into two parts. In the first part, the whole number of participants was split into small break-out rooms so that every participant had the chance to give his inputs and participate at the discussions. For each break-out rooms a moderator was defined who guided through this part of the workshop. Target was to identify the best idea from the point of view of the participants out of each break-out room.

In the second part of the workshop, each break-out room moderator presented their best idea and within the whole group of participants there was an evaluation resp. selection based on votes.

The basic methodology for guiding the discussions and evaluation of ideas during the break-out room sessions as well as during the overall session is visualized by the following figure.

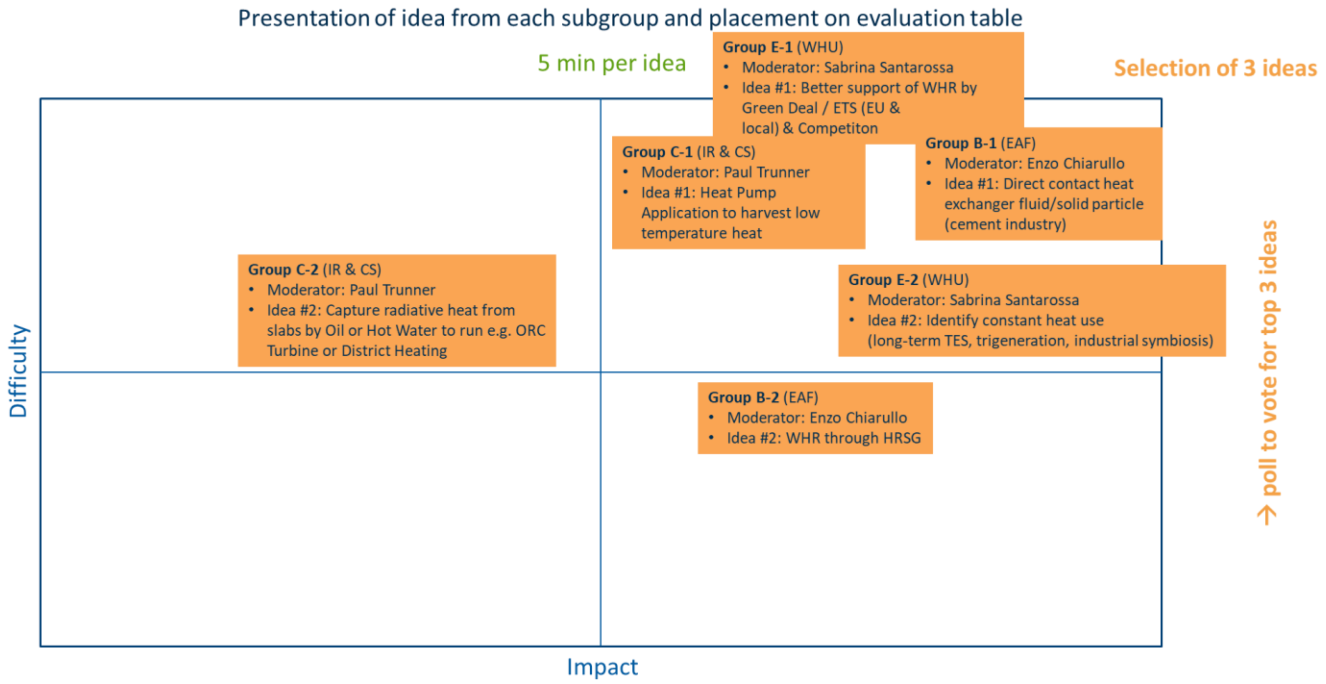


In the following an overview of the participants and working groups is given. Each break-out room was dedicated to a technological area/field and each group derived two (2) ideas to improve the current situation.

#	Possible Groupings / Break-out Rooms	Moderator	Participants	Number of Participants
B	Electric Steelmaking	Enzo Chiarullo / Agnieszka Morillon	1. Alen Sest 2. Alessandro Dallasta 3. Dirk Kusters 4. Gerard Griffay 5. Nikolaj Sonjak 6. Virpi Leinonen	**8**
C	Ironmaking & Converter Steelmaking & Casting & Rolling	Paul Trunner	1. Alessandro Foresti 2. Bianchi Ottini 3. H. Ibrahim 4. Pavel Ivashechkin	**5**
E	Waste Heat Utilization & Legal Constraints	Sabrina Santarossa	1. Alex Bertrand 2. Frank Mintus 3. Gorazd Ravnik 4. Konstantinos Kollias 5. Mercedes Tecnalia 6. Olivier Bregand 7. Raul Aragnoes 8. Thomas Keplinger	**9**

Derived Ideas in Break-out Rooms & Joint Evaluation

Each break-out room derived 2 ideas which were then jointly evaluated in terms of impact and difficulty. An overview on the derived ideas is given by the following figure.



After the presentations of the ideas a voting was done to identify the 3 best ideas according to the view of the participants. The ideas are summarized in the following.

#	Idea	Why?	How?	Who?
1	E1: **WHR Clarification for Green Deal/ETS** • *Better support of WHR by Green Deal / ETS (EU & local) & Competition*	• Possibility to incentive WHR projects (reducing PBT) • Unclear market situation for WHR on energy market	• EU comm. should commit to WHR (e.g. specific projects) • Clarify competition between companies vs. green deal incentives & ETS ➢ **Lobbing activities (EU level)**	• EU • Local government • ESTEP • EUROFER
2	C2: **Radiative Heat Recovery from Slabs** • *Capture radiative heat from slabs by Oil or Hot Water to run e.g. ORC Turbine or District Heating*	• Utilize heat from slabs • No risk for steelmaking process • (rather) easy to install • Easy to convince operator	• Panels above slabs at outlet of CCM • Heat up Water or Oil • Promote demonstration project at selected plant ➢ **Joint R&D project**	• Company with experience of Heat recovery • Steelmaker with CCM • EU auction
3	E2: **Identify constant heat use** • *Identify constant heat use (long-term TES, trigeneration, industrial symbiosis)*	• Maximize the use of waste heat along the year • Possibility to incentive WHR/TES projects (reducing PBT)	• Find heat sinks in summer • R&D efforts for thermal energy storage (high temperature & long-term) ➢ Heat sinks **mapping & Lobbing activities (local level)** ➢ Thermal energy storage: **Joint R&D project:**	• Industry • Local community

Summary & Link with Clean Steel Partnership

The webinar series demonstrated that there are significant activities in the area of waste heat recovery and utilization ongoing in European Iron & Steel Industry.

Whereas the workshop showed that there are still technoeconomic challenges which have to been solved. The main challenges and possible solutions to overcome them derived during the workshop session, are summarized below:

- Green Deal / ETS: Waste heat recovery is still not addressed in satisfying way in the ETS as well as Green Deal according to the participants view. Furthermore, WHR is not reflected in a proper way considering the overall energy market situation and competition conflicts between different “green” technologies could arise. Hence, it is recommended to intensify lobbying activities by ESTEP or similar organizations towards this direction.
- Heat recovery from slabs: Besides the already known waste heat sources within a steel plant, radiative heat recovery from slabs seems to be one of the heat sources which needs further investigation to develop technical and economical feasible solutions. Hence, it is recommended to set-up dedicated R&D projects on this topic.
- Constant heat use: A topic which is strongly influenced by technical as well as economic cross-sector thinking is the proper usage of waste heat heat. From technical point of view further investigation for the development of thermal energy storage systems are necessary (especially for long-term energy storage) to combine heat sources from the steel plant with available heat sinks in other industries or communities. Besides these technical R&D activities, local activities in identifying suitable heat sinks as well as promoting them will be necessary.

The table below clusters the different topics which have been addressed during the webinars and workshop and links these clusters with the Building Blocks of the Clean Steel Partnership Roadmap.

Area of Interest	**Key Aspect and Scope**	**Presented Topics**	**TRL**	**CSP link**
Industrial Waste Heat Recovery	• Waste heat recovery solutions with various references	• Industrial waste heat recovery solutions (EAF, sinter cooler) • Waste heat utilization examples (district heating, electric power generation via ORC modules or steam turbines)	9	• BB#7 heat generation process
Advanced Waste Heat Recovery Solutions	• Waste heat recovery solutions with limited references • Some solutions partially under development	• Heat recovery from slags, slabs, etc. • Thermoelectric modules • Thermal energy storage solutions	4-8	• BB#7 Heat generation process • BB#8 Energy management / Energy vector storage

				• BB#9 Steel specific circular economy solutions
"Waste Heat Economy"	• Market regulations • Funding schemes (Green Deal, ETS, etc.)	• Waste heat integration • Workshop discussions	7	• BB#8 Energy management / Energy vector storage

Abbreviations

BB	Building Block
CCM	Continuous Casting Machine
EAF	Electric Arc Furnace
ESTEP	European Steel Technology Platform
ETS	Emission Trading System
EU	European Union
ORC	Organic Rankine Cycle
TES	Thermal Energy Storage
WHR	Waste Heat Recovery
WHU	Waste Heat Utilization