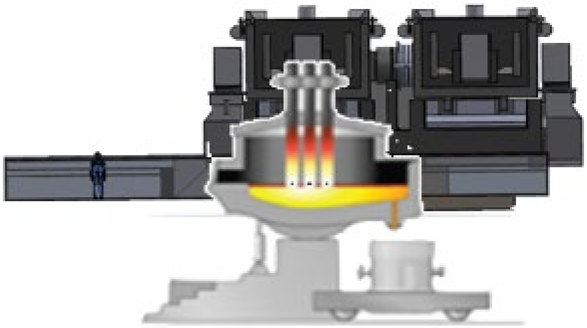
Information for steel plant managers



New Extended Concept for Green House Gas Emission Control and Energy Saving in Steel Production.

Developed and assembled by eco-e AG

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MANAGEMENT SUMMARY

1.1 PREFACE

The world steel production comprises in 2020 approx. 1'864 million tonnes. Steel is used in all kinds of industries, such as building and infrastructure (52%), mechanical equipment (16%), automotive (12%), metal products (10%), other transport (5%), electrical equipment (3%), and domestic appliances (2%).

Steel is a recyclable material. The base materials of steel, carbon and iron are among the most abundant elements in the universe and the most abundant elements on earth.

To produce 1 tonne of steel out of scrap (largest recyclable part of the waste) approximately 700 kWh are needed.

Since the 60's great efforts are ongoing to improve the Electric Arc Furnace (EAF) technology.

The declared main objectives in EAF improvements are:

- Reduction of energy demand
- Reduction of green house gas (GHG) emissions
- Reduction of electrode consumption
- Increase of productivity.

1.2 SOLUTION

Our process technology is a naturally efficient and ecologically friendly recuperation of the waste heat. There are no mechanical elements in the flow of preheated scrap to the furnace. It offers many safety and process advantages missed in the known solutions. The fossil energy contained in the scrap (pollutants) supports the scrap preheating. All kind of toxic and harmful combustion products are burnt within the preheating process. The furnace atmosphere is controlled to maintain a high CO ratio in the furnace. This CO is then fully reacting within the scrap, producing such the most efficiency.

1.3 IN THE SIGHT OF STEEL PLANT MANAGERS

The proposed solutions offer a quick return on investment (ROI) in less than 18 months after start-up. Each solution consists of two steps, a thermal upgrade of the furnace and a transformation of the post-combustion chamber into a scrap preheating unit.

The steps, individually crafted, are designed, produced, erected, and started up in less than 30 months after contract signature. The interrupt of the production for start-up is less than 30 days.

Savings can be achieved in energy consumption, greenhouse gas emissions, consumables, and work (maintenance). Depending on the energy price, the savings can be considerable. The modified plant also gains flexibility, e.g., preheated scrap can be stored to bridge an interruption, etc., versatility, e.g., storage of third-party raw materials such as DRI, and independence.

The total investment for the proposed solutions varies between 0.5 to 10 Mio € depending on plant size, chosen solution, and engagement (Engineering, EPC, or Turnkey).

All ECOFEEDER solutions are based on the existing furnace, they all charge the scrap in the middle of the furnace and the furnace can operate occasionally without preheating scrap. The connection on variants MF, CF and P are strictly for scrap charging.

2. Technical Background

1.1 Steel making

We can divide steel production into two main routes – the **ore route** and the **recycling route.** The primary steel route, which currently produces pig iron in blast furnaces and refines in converters will possibly be modified into DRI-EAF-Converter plants to reduce the greenhouse gas emissions. This new primary steel route is then based on direct reduced iron (DRI) and some scrap, mainly internal scrap. The secondary steel route, the recycling route, uses more return scrap, end-of-life scrap and some DRI.

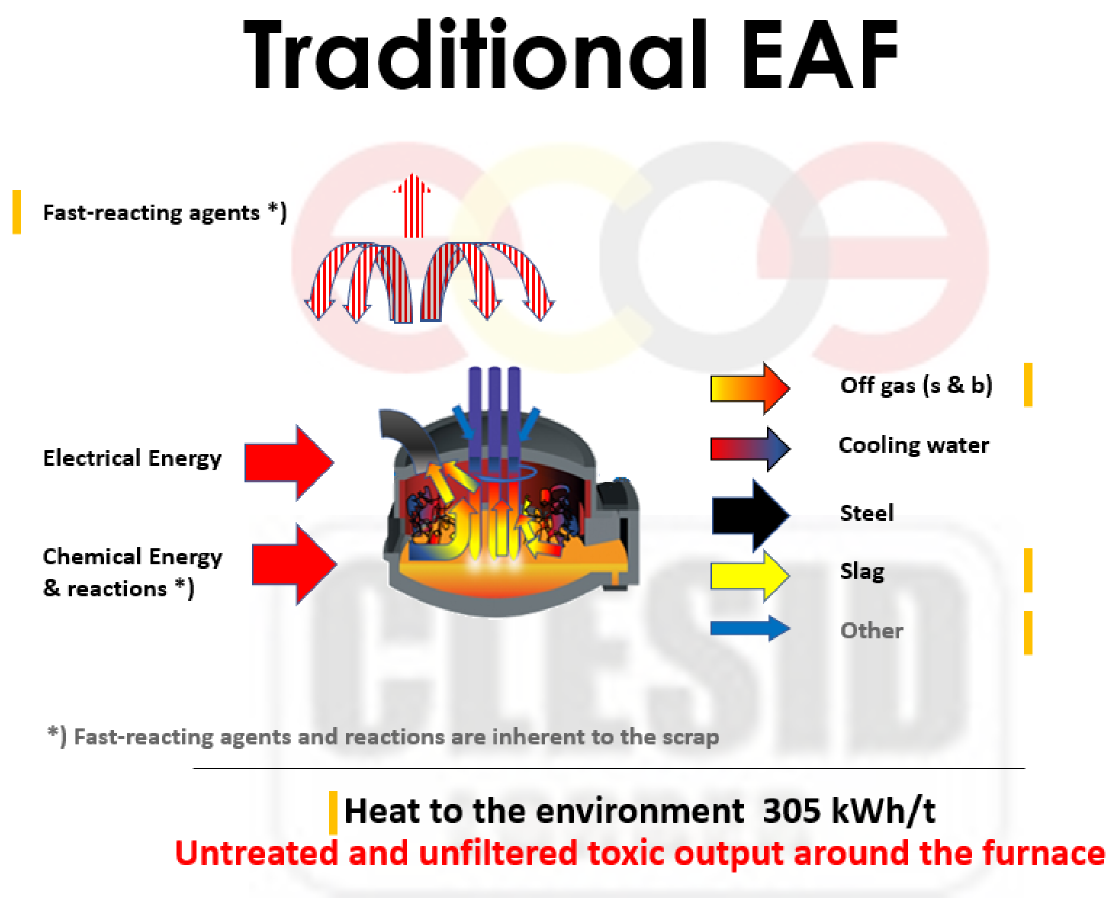
Consequently, as steel production increases (from 200 Mt in 1950 to 1864 Mt in 2020), the amount of end-of-life scrap also increases with a time lag.

Worldwide 28% (560MT out of 1684MT) of the steel production is being produced by recycling. In Europe, the rate is as high as 41% (65MT out of 159MT).

A mini mill, short for a recycling steelwork, consists of a scrap yard, electric arc furnaces (EAF), a secondary metallurgy consisting of a ladle furnace (LF) and case wise of a vacuum degassing installation or other ladle treatment stations and continuous casters.

2.1.1 State-of-the-art Electric Arc Furnace (EAF)

The energetic balance of a traditional EAF



Process balance:	
Energy balance furnace	720 kWh/t
Real energy input	630 kWh/t
Profit (Steel)	385 kWh/t
Heat recovery	0 kWh/t

Since the 60's the main objectives of technical improvements of Electric Arc Furnace (EAF) technology are:

- Reduction of the electric energy demand
- Reduction of the electrode consumption
- Increase of the productivity and/or increase of the efficiency

The EAF vessel consist of three major parts, the lower shell, the upper shell, and the roof. The usual shape of the EAF is round. For tapping the liquid steel there are various solutions which influence the appearance of the EAF. Here some examples: the open spout tapping (OST), the submerged spout tapping (SST), the eccentric bottom tapping (EBT), off-centre bottom tapping (OBT), centre bottom tapping (CBT) and others. Further there are basically two scrap charging possibilities the asymmetric and the symmetric charging. The asymmetric charging, mainly due to a side shaft type scrap preheating, requests an adapted form and adapted melting procedures.

The size of the upper shell is adapted to the scrap charging method - either a single bucket charge (very high upper shell) or a 2- or 3- bucket charge. The advantage of the 1- bucket charge is, that the cover must be opened only once per heat, while two or three bucket charges need a corresponding number of roof openings. Each opening of the roof goes along with an energy loss (~10 kWh/t. The major loss, however, is the loss of the energy inherent to the pollutants and reactions, which are burning off at every charge (~30kWh/t).

Typical furnace values:

Type	Electricity	Chemicals	Heat loses	Electrode	Pon	Prod.
	[kWh/t]	[kWh/t]	[kWh/t]	[kg/t]	[mins]	t/h
2- to 3-basket charging	420	280	256	1.5	38	1.25
Single-basket charging	380	280	240	1.6	34	1.36

2.1.2 Scrap preheating

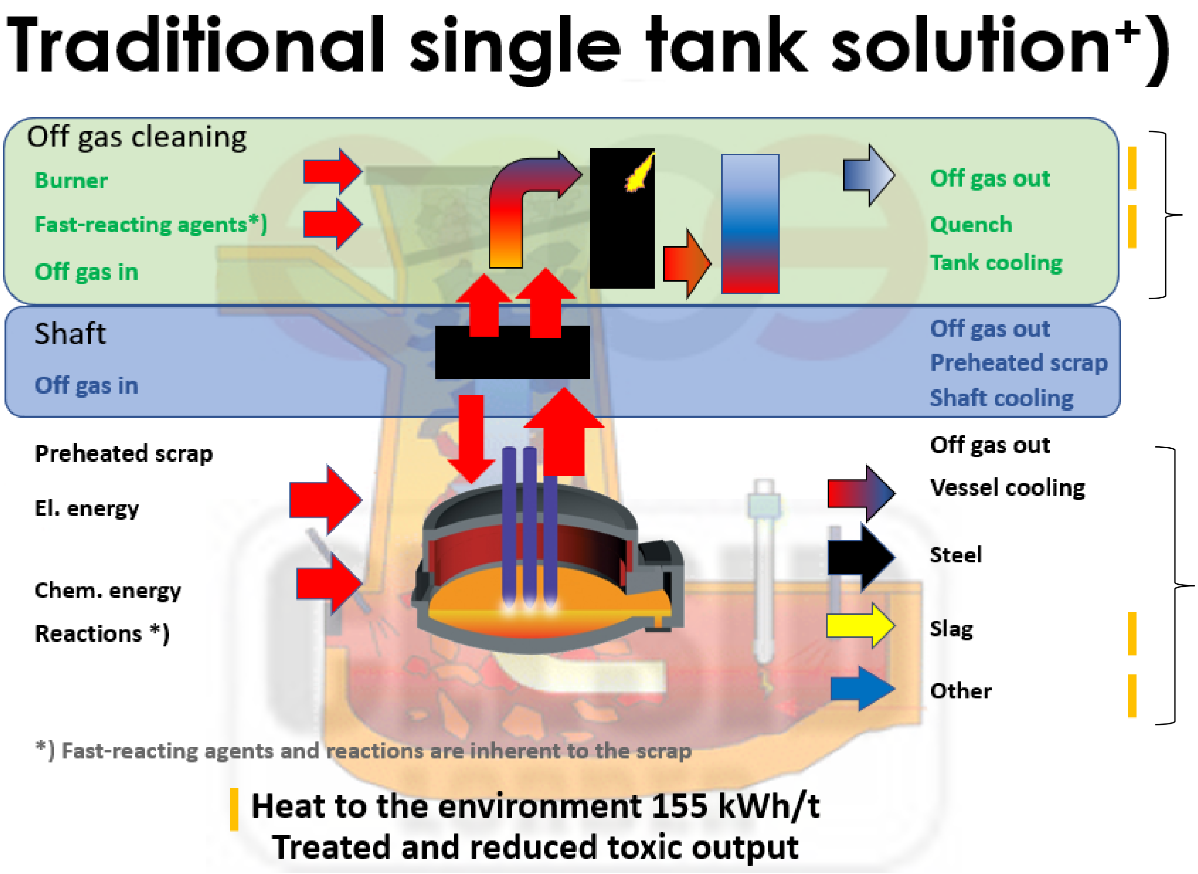
Continuously increasing electric energy costs have encouraged engineers of the electric furnace producers to think about recuperation of the energy waste.

Scrap preheating has had its first appearance in the 80's. One of the first well working idea was the shaft furnace. The shaft furnace consists of a vertical shaft with retaining elements at the bottom and a gate on top. Through the top gate the cold scrap is charged. There are various types of shaft designs.

This preheating procedure uses the hot gas leaving the furnace, to heat the scrap piled in the shaft. In this way the waste energy which is usually released to the environment (37%), is partially used to reheat the scrap. This reduces the electrical energy input directly.

The scrap is hold back by water-cooled fingers and released into the furnace when required. These fingers represent a weak item in the shaft construction, as they are exposed to a high wear, and they consume a lot of energy (cooling).

The energy balance of an EAF with a single tank scrap preheating (e.g., all types of shaft and conveyor systems)



⁺) These values refer to an existing shaft EAF

Lost energy: Fast-reacting agents, after burning of combustion products, Quench, aux power (approx. 40kWh/t)

Process balance:

Energy balance furnace	688 kWh/t
Real energy input	597 kWh/t
Profit (Steel)	304 kWh/t
Off-gas cleaning	120 kWh/t
Scrap preheating	162 kWh/t
Energy recuperation	76 kWh/t
Efficiency	27%

Reusable energy: Furnace cooling, shaft cooling, tank cooling

Typical furnace values:

Type	Electricity	Chemicals	Heat loses	Electrode	Pon	Prod.
	[kWh/t]	[kWh/t]	[kWh/t]	[kg/t]	[mins]	
2- to 3-basket charging	420	280	256	1.5	38	1.25
Single-basket charging	380	280	240	1.6	34	1.36
Shaft furnace	330	205	123	1.4	32	1.40

2.1.3 Conclusion

As one may see out of the presented figures, there is an impressive difference between an EAF without scrap preheating and an EAF with scrap preheating. But there are more and more stringent environmental regulations which represent a problem to most of the existing scrap preheating projects. Consequently, there must be a new, better solution to continue this road.

2.1.4 Outlook

Today steel makers are seeking for economically favourable, ecologically friendly, and pragmatic solutions. These are the main objectives for maintaining commercial success and competitiveness in this sector.

There are various solutions available in scrap preheating. Some which are, rendering good service at high maintenance costs, others which are with little maintenance but with some environmental issues and installations with limited productivity and solutions, which require new buildings and/or high revamping costs.

Together with our consultants who are since ages in steel, we have analysed all the existing scrap preheating solutions, and we are proud to present herewith our solution.

3. THE NATURALLY EFFICIENT AND ECOLOGICALLY FRIENDLY SCRAP PREHEATING SOLUTION BASED ON ENERGY LEVERAGE

3.1 THE ECO-E TECH – THE STATE-OF-THE-ART

Analysing the shaft-furnace technology, disadvantages were found in the retention system of the preheated scrap with water-cooled fingers, in the interrupted pre-heating of the scrap due to the discontinued scrap charging, in an unequally preheating throughout the scrap surface, in cold scrap layers alongside of the cooled shaft walls and of course in the environmental issues around the toxic and harmful combustion products which are produced while heating the cold scrap.

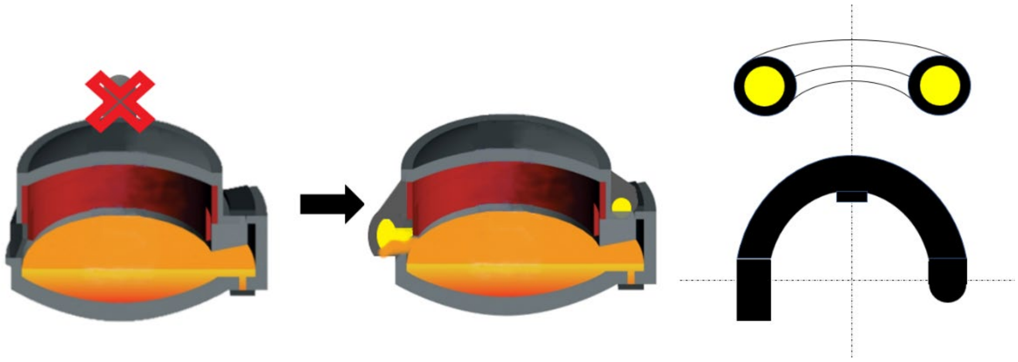
The **eco-e tech** bases on new findings on the continuity of the gas flow in the furnace, the heat transfer from gas to material, the controlled post-combustion of the CO, the advantage of changing gas velocities, the ecologically friendly after-burning of the combustion products and dispenses with all kinds of retention systems. The pre-heating happens in the horizontal, and the scrap is charged by means of a kipper system. There are concepts to fill the scrap into the furnace through the open roof and others where the scrap is charged through a closed connection which serves only for scrap supply and never for off gas takeout. **eco-e tech** therefore consists of two parts the furnace part and the preheating part.

Perhaps the most important difference from other preheating systems is to take up the idea of the post-combustion or sparkling chamber existing on all traditional arc furnaces. This chamber is responsible for the post-combustion of CO, the killing of the sparks, the settling of most of the dust by simply expanding the off gas. This and more happens in our first preheating container.

Another not less important difference is the modification of the thermal flow within the furnace. At a natural fire, fumes carry away most of the energy produced by the combustion. The direct effect of the combustion is reduced to the radiation. The hot fumes mix to the ambient air and the energy is gone, unless the hot fumes are conducted in a duct system, acting as heat exchanger. The fire in an open fireplace burns slowly, the efficiency is marginal and the reason why we put stones around the fire is to get at least a little bit of the energy stored. However, our furnaces are not open fireplaces, they are closed high-temperature containers designed to melt scrap, so the main goal is to keep as much energy inside as possible to reduce the cold air import or to melt the scrap as quickly as possible.

3.1.1 The Torus Off-Gas Duct

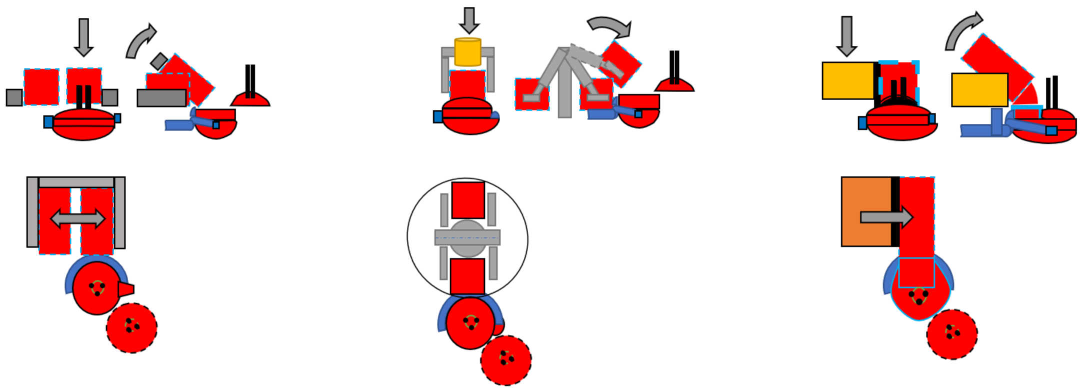
Considering that the total energy input to melt steel ranges between 680 and 800 kWh/t and that the economic output is around 400 kWh/t, the off gas represents the most important energy carrier beside the steel. Reason enough to consider the off gas more seriously. Taking up the energy flow described here above it is hardly understandable why modern electric arc furnaces are built the way they are. The 4th hole is the natural outlet, and this is perfectly ok with a convection furnace, but is it the right outlet for the off gas in a furnace with forced suction? No, for many reasons we propose a new off-gas outlet at ‘scrap-level’. The Torus.



For the steel plant this is a modification with a real more-value because it is reversible. The comparison between existing and new can be made at any time. By a simple change from the roof with the 4th hole to the roof without. Th lift-off of the torus ring, the reinstallation of the slag-door, the change of the EBT-cover, and the closure of the corresponding opening at the combustion chamber. The change is feasible within a maintenance shift.

Without further going into the details, here the different members of the eco-e tech family. Each design has its specialities, but all are fully working scrap preheating installations. And the best, the placement of the second container is flexible, which means that the arrangement fits with your steel-plant, call it tailor made.

3.1.2 The ECOFEEDER Family

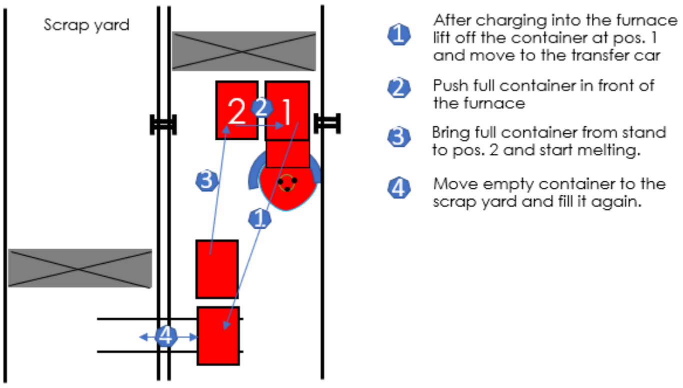


ECOFEEDER E, MC | ECOFEEDER T | ECOFEEDER P

Here a little bit more about the different members of the family. At the right the original ECOSHAFT now in a new version, the ECOFEEDER P. The new ECOFEEDER P is a simple ‘lift off’ and ‘replace’ solution ideal for very narrow layouts.

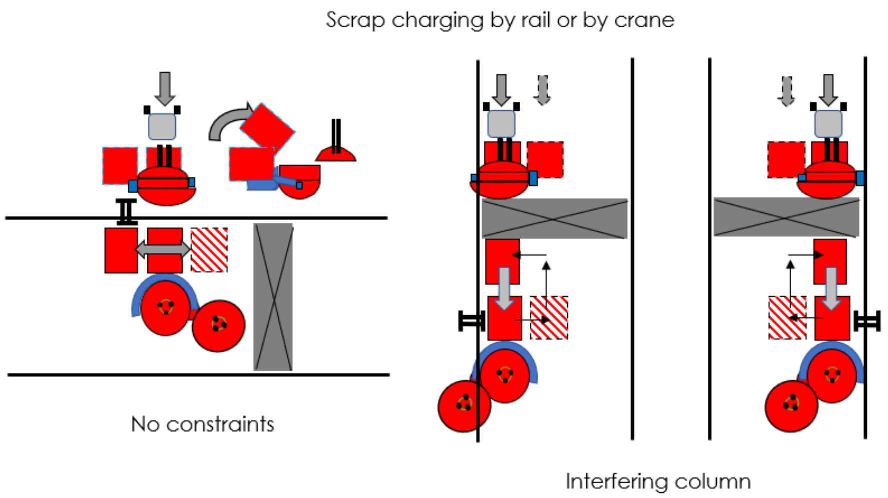
3.1.3 The ECOFEEDER Flexibility

Container movement (no scrap basket needed)



ECOFEEDER P

The 'simplest' solution - the ECOFEEDER E – adds to your existing furnace. It charges through the open roof same as your existing basket, of course you may add internal heavy scrap with your basket once there is a hot heel.



ECOFEEDER E, MC

The ECOFEEDER E can be replaced with the MC model if opening the furnace roof is not wanted. The loss when opening (radiation and convection) is much lower than the loss with cooling of the shaft at 'shaft-furnaces'. Note: Opening the roof of a furnace to add preheated scrap is not comparable to opening the roof for cold scrap charging.

The eco-e tech is as versatile as your existing furnace, that means you can continue to use hot iron if you already did so, you may also add DRI, if you did it till now. With the ECOFEEDER family you can use the same variety of scrap as you did till now, and you can add internal or return scrap (high density) as well as before. There is almost no limit. In contrary, you can preheat DRI (special installation) and keep it hot in a container or tight conveyor belt flooded by the residual off gas of the eco-e tech – no limits!

Another exiting tool is the 'cool tip' electrode. An active CCU (carbon capture and use) application with astonishing effects. The pyrolysis when heating of CO_2 above 2000K, the arc temperature is at about 3500K, cools down the electrode tip and the produced CO helps maintaining the foam of the slag at times when there is no or little CO production at the steel slag interface. This CO reacts into CO_2 in the preheating container and releases approx. 2.8 kWh/kgCO_2. Astonishing, right?

Here a list of some interesting details:

	Unit	eco-e tech
Specific el. energy input	kWh/t	<250
CO_2 emissions	kg/t	<20
NG	m^3/t	<4
Cold spot burners	-	No need
Mech. elements to hold or transport scrap	-	No
Number of preheating containers	-	2
Residual off-gas temperature *)	°C	~ 600
Post combustion	-	Included
Lower limit scrap density	t/m^3	0.5
Higher limit scrap density	t/m^3	1.4
Elimination of combustion products (VOC, dioxin, furans, etc.)	-	By burning
Workshop erection and commissioning		yes
Prod. interrupt for start-up	days	< 30
Maintenance frequency (use and repair)		Low
Dust in residual off gas		Very low
Est. investment cost *)	Mio €	<12

*) estimated figures

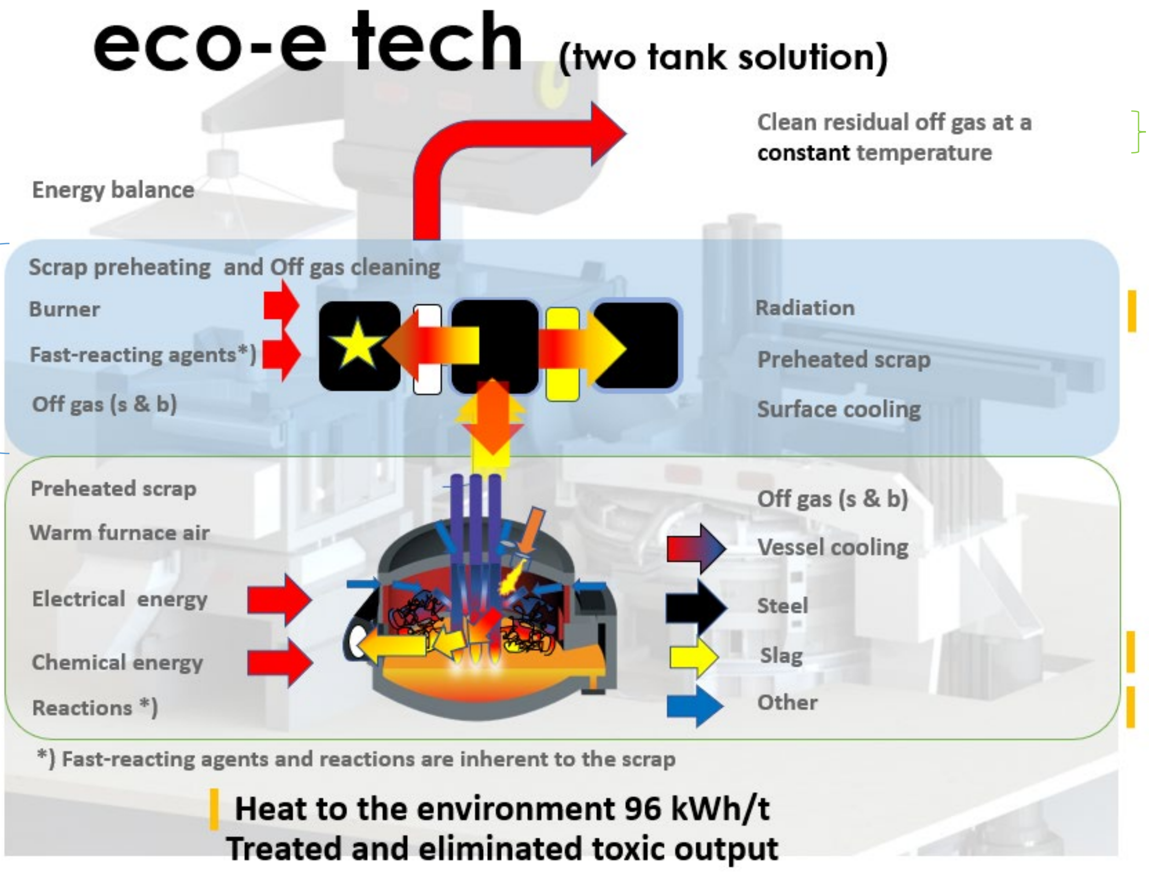
The main advantages of the **eco-e tech** are:

- The **eco-e tech** offers a new, thermally more efficient off-gas system.
  The new Torus off-gas system allows a better use of the thermal energy of the off gas. The fully controlled 'false' air input allows to optimize the furnace atmosphere for less thermal losses, less electrode consumption, higher CO content for the post combustion in the scrap preheating, less dust emission, and lower energy consumption.
- Reliable and uninfluenced off gas analysis
  The off-gas analysis at traditional furnaces is influenced by the ambient air intake at the furnace rim and around the electrode holes. This air falsifies the oxygen content of the off-gas and returns wrong values. Furthermore, it fills in no time with dust and becomes quickly unusable. The intake of the off-gas system at the Torus system is far away from the 'false' air intakes and well protected against dust setting.
- Optimized preheating.
  The scrap is preheated in a cascade way. First, the cold scrap is warmed and cleaned of pollutants. The off gas cooled by the energy transmission is reheated to crack the toxic and harmful compounds. This reheated gas is then directed to the second container full of already cleaned scrap. Considering the off-gas flow velocity, there is enough time to

burn the basic elements of the compounds when the off gas reaches the second container. The off gas then flows trough the scrap in the second container and transmits part of its energy to the scrap. Once the combustion in the first container is over, the containers are changed. The off gas coming from the furnace further heats the scrap. As there are no pollutants anymore in the scrap, the reheating of the cooled gas can be omitted. To prevent oxidizing of the scrap, post combustion is only initiated in the second container. This heats again the cleaned scrap (previous step). As soon as the wanted temperature is reached, the scrap is charged into the furnace and cold scrap filled again in the by then empty container.

- Ecologically and economically friendly preheating means no excessive oxidation.
  To effectively and fast heating the cold scrap the post combustion is needed in the first step at the first container, in the second step the post-combustion is suppressed in the first container and only allowed in the second container. There, already cleaned scrap is further heated by post combustion.
- Marginally higher yield.
  Due to the horizontal preheating, the low off-gas speed in the containers, the fast melting (high pre-heating temperature), and refining with arcing mostly under foaming slag there is very little iron oxide escaping, thus the yield is marginally higher.
- No problem with icy, snow laden scrap.
  Water can become a serious issue in electric arc furnaces especially when ice and water is enclosed in the scrap. This cannot happen with **eco-e tech**.
- Less dust.
  Already in the furnace the dust which is stirred up by the arcing passes through the mushy scrap before leaving the furnace through the Torus. Then in the preheating container more dust will settle down due to low off-gas speed. This way the scrap acts as a filter, and the dust is returning together with the preheated scrap into the furnace.
- No scrap pusher, no holding fingers.
  Mechanical parts need maintenance, especially when they are close to molten steel.
- Almost no scrap size limitation, use of light and heavy scrap is possible.
  The use of light scrap allows us to reduce the prime costs. In case of very light scrap ($<0.4 t/m^3$) a baler/shear is recommended to compact this scrap to a density of about $0.6 t/m^3$. Heavy scrap may be charged through the open roof at any time, preferably when there is a hot heel. The advantage of the Torus system is that the off gas is also sucked of even when opening the roof.
- Flexible arrangement and low construction height.
  The **eco-e tech** fits at almost any existing furnace situation without need for new buildings, crane tracks or special hoists.
- Possibility to melt traditionally and in scrap preheating mode
  This unique flexibility allows to combine special steel making and mass steel production.

The energy balance of **eco-e tech** (example)



eco-e tech uses the energy of the off-gas and off-gas cleaning actively (Fast-reacting agents, heat, post-combustion, and after burning of combustion products).

Process balance:	
Energy balance furnace	680 kWh/t
Real energy input	477 kWh/t
Profit (Steel & rest energy)	461 kWh/t
Scrap preheating	266 kWh/t
Energy recuperation	159 kWh/t
Efficiency	60%

Use of **residual energy** due to clean and dust-free off gas for multiple use such as steam production, distant heating, electricity by ORC, etc.

Provided the furnaces would be the same, how is it then possible to get a higher preheating temperature? Here the answers:

- eco-e tech takes advantage of the fast-reacting agents like pollutions, carbon and others inherent to the scrap (~30 kWh/t_{Scrap}) for scrap preheating.
- eco-e tech controls the CO content in the furnace to fully benefit of the post combustion (PC) at the scrap preheating (~70 kWh/$t_{Liquid\ Steel}$)
- the burners to heat the combustion products to their cracking point are supporting the scrap preheating (~45 kWh/$t_{Liquid\ Steel}$)
- **eco-e tech measures the combustion of the pollutants, controls the burners accordingly and changes containers to optimize the heat transfer to the scrap.**
- eco-e tech applies a special technic to cool electrode tips (CCU) and to increase the CO content in the furnace atmosphere.
- eco-e tech uses forced surface cooling for the containers to heat the furnace air.
- **eco-e tech benefits of a better heat transmission based on low off-gas speed due to large cross section change.**

3.2 Scope of the ECO-E Tech

3.2.1 Torus off gas evacuation

3.2.1.1 Existing material

This modification can be seen as extension of the existing material, that means the existing material remains. The ground plate of the elbow on the spare roof is removed and the corresponding panels of the roof are replaced by new panels. If a 'shaft-type' scrap supply is chosen, these panels must be openable. For this some modification on the roof are need.

There are some modifications needed on the cover of the EBT and on the panel underneath the 4th hole. The existing slag door and its lifting mechanism must be removed. To support the torus some pads are fixed on the support of the upper shell.

The existing burners and lances will be rearranged to suit Torus requirements.

There is a modification needed at the existing combustion chamber. A new off gas entrance must be made. The new entrance shall be identical with the existing, so that each roof can be chosen on purpose. At last, the connection and the slider must be adapted.

3.2.1.2 New material

The Torus with a span from the EBT to the slag door will be provided. The part in front of the slag tunnel is tiltable, so that slag tunnel can be reached. The torus lays on the pads attached on the supports of the upper shell. The Torus will be fixed and secured.

3.2.2 ECOFEEDER

3.2.2.1 Common material base

The ECOFEEDER consists of 2 (two) containers and a platform where the containers move. The area in front of the furnace is equipped with a kipper grid with closures for the container. Underneath the platform there are the burner chamber, the hydraulic station, the electric room, and the off-gas ducts with its registers. The containers are identical. They are made of a steel case designed to get a lining with specially designed and fabricated refractory plates (propriety material). The contains have inlets and outlets for the off gas, a front door, and a chute for the scrap supply.
The hydraulic room, the electro room, the platform, the containers and the ducts are pre-erected elements, which are preassembled and tested at the workshop.

3.2.3 ECOFEEDER-P

3.2.3.1 Existing furnace

Beside the modification described here above (3.2.1) no changes are made on the existing furnace.

3.2.3.2 Adaptation

The **ECOFEEDER-P** is the only model where the containers are moved around by the OHC. Here a transfer car from the furnace bay to the scrap yard and an intermediate stand must be provided. Beside that only foundations must be made for the platform.

3.2.4 ECOFEEDER-MC, E

3.2.4.1 Existing furnace

Beside the modification described here above (3.2.1) no changes are made on the existing furnace.

3.3 Cost Estimation

(Example for a 90t EAF with a yearly production of 800'000t).
Exclusions: Foundations, any supply and work outside the battery limit

Price indication [k€] (Estimated values, subject to a study*))	Engineering	EPC (Engineering, procurement, commissioning)	Turnkey
Torus off gas system	500	1'100	2'200
ECOFEEDER E	1'600	5'000	8'400
ECOFEEDER M	1'800	6'000	9'600
ECOFEEDER P	1'400	4'500	8'000

The above prices exclude any modification, replacement, reorganisation and/or adaptation of exiting material, piping and supply of media outside of battery limit, civil works and software engineering to adapt the existing programs and processes.

All price indications are estimations and may vary according to local conditions and availabilities.

*) Feasibility study

We offer a study to evaluate and check the feasibility, prepare a layout with your specific requirements, make all calculation to find out the energy savings and environmental impact, and prepare a detailed offer completed with a timetable for your steelworks. This study will be made on a paid basis.

The cost for this study is depending on customer's requirement and the scope of work. Here an indication of the cost for a feasibility study 150'000 Euro

In case of an order, the cost of this study will be partially credited.

4. In the Sight of the Steel Plant Manager

4.1 Risk

In the past scrap preheating has always been connected to an environmental issue. Many scrap preheating installations have had severe problems complying the clean air act. Many installations had to be closed, since by respecting the clean air act the production costs were not anymore economic.
eco-e tech allows to respect the clean air act by a procedure which is well applicated in the cement industry. **eco-e tech** incinerates the base elements of the toxic compounds and eliminates the bad smell of the VOC and NOx by the integrated heating of the off gas after burning the pollutants in the first container system and the dwell time in the second container after reheating.

4.2 Sight in the Future

As 2030 and 2050 approaches fast, provisions must be made to minimise the emission of heat to the environment, to reduce the CO_2 emittance and renounce to the use of fossil fuels wherever possible. We can actively reduce the unnecessary emittance of heat and CO_2 by installing installations with a high effectivity. The **eco-e tech** offers a better thermal exploitation of the furnace, offers a clean and economically viable scrap preheating, proposes conserving the heat of previously preheated DRI, allows the application of heat exchangers with almost dust free off gas, foresees the application of hydrogen/oxygen burners as soon as available, offers the possibility to cover the panels in the furnace with thin reinforced refractory panels to reduce the export of heat by cooling water. **eco-e** is pioneer in energy saving solutions.

4.3 The Return On Investment (ROI)

The realisation of an **eco-e tech** project consists of an engineering, realisation, and payback phase. The investment, step by step, covers the first phase. After PAC, as the production ramps up, the payback period starts. ROI should be reached depending on the daily production within 6 to 12 months.
It is advisable to clear in detail about the production and overhead costs to be able to evaluate the benefits of the **eco-e tech** by ordering a relevant study to be elaborated by eco-e.

4.4 Production

With eco-e tech the production would not be in danger at any time. The versatility, flexibility and economic efficiency allows to produce with the least energy input and the least GHG emissions whatever happens.