GREENSTEEL

The way to the future

ABSTRACT

Is it possible to convert an existing EAF with poor off-gas utilisation into a highly efficient energy saving and environmentally friendly furnace without mayor changes in buildings and facilities? Here a way to a low emission steel ('GreenSteel') plant able to reach net zero target profitably.

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GREENSTEEL – THE WAY TO THE FUTURE

Summary

The medium- and short-term issues that concern us are climate change and the war. We seem to be powerless against both. Both have a common denominator – energy saving. Energy saving to break dependencies and energy saving to reduce CO_2 levels and thus curb global warming.

GreenSteel – a much-used and much-quoted expression, a kind of black box. By GreenSteel we mean the production of steel with particularly low emission values, maximum reduction of CO_2 emissions, minimum energy input, optimal exhaust gas and residual heat utilization, i.e., energy saving!

'To be or not to be' - how true and up to date is this saying, be it in front of the world backdrop or be it 'only' for the heating of your own 4 walls. And how true is it for procrastinating and postponing decisions; but everyday counts because everyday thousands of tons of CO_2 are emitted, and global warming is constantly increasing. Storms, droughts, floods are the signs of an increasingly agitated meteorological activity, and we are also quite powerless by this.

With a short business plan, we would like to show a way in which an existing electric arc furnace can be converted stepwise with minimal impairment, limited resources, and a good planning into a 'GreenSteel'-plant with **minimal emissions** and **minimal energy input** per ton of liquid steel.

The advantages of the eco-e concept are manifold and convincing – there is a way for every existing electric arc furnace and there are convincing arguments for 'green' or 'brown-field' project. Saving energy concerns us all!

> **Conclusion**: The eco-e tech concept allows an existing production facility with poor exhaust gas utilization to be gradually converted into an efficient plant that can achieve the goal of 'climate neutrality' well before the deadline and is commercially profitable.

Challenge us and let us explain the advantages to you. We are looking forward to an interesting conversation.

Order a feasibility study today.

Topics of the time – climate neutrality and energy saving

Our governments – especially in Europe – encourage people to save energy to prevent any shortages. Our governments – most of the world – have pledged to reduce Green House Gas (GHG) emissions, especially CO_2, by 2050 to such an extent that global warming does not exceed the 1.5°C previously set. Will we be able to achieve this goal? At the last climate conference, it was soberingly stated that the goal is unlikely to be achieved, and if only with certain compromises and probably at a later date!

Already in the Middle Ages, Shakespeare put the word 'to be or not to be' in his protagonist's mouth as an expression of **procrastination** and **postponement** of problems – is the protagonist synonymous with the industrial nations of our time? The pursuit of wealth and power is devouring more and more of our vital resources and heating up our planet more and more. No, this realization is not an ode for a political direction – but if politics already encourages people to save energy, it should also warn industry, and rightly so, because it would be possible to act quickly, effectively and without large funds and new buildings. We show this using a short business plan later in this article.

The term '**GreenSteel**' is not limited to the reduction of CO_2 emissions in steel production, no, it includes much more, namely the environmentally friendly processing of the gases produced during the combustion of impurities inherent to the scrap such as plastic, paint coatings, oils and fats, organic substances, etc., the most comprehensive use of exhaust gases and bound energy and, of course, the use of residual heat, so that ideally only a 'marginal' environmental impact remains. The carriers with energy that is difficult to trace are the slag, the Ohm's losses (conduction and transformer waste heat), the cooling of the furnace body and the radiation losses when the furnace lid is open. This residual amount should not be greater than 100kWh/tFS!

Saving energy – the order of the day or the specter of this unspeakable war – we are dependent not only as a result of globalization (see Covid), but also on natural resources that are in the hands of a few and that ruthlessly use this good as a means of exerting pressure. Saving energy – a topic that is not yet very important in the electric arc furnace, considering that about 300kWh/$t_{\text{Liquid Steel}}$ (t_{LS}) is released unused into the environment during steel production.

In 2020, 140 million tons of crude steel were produced in Europe[i] . The proportion of electric steel is about 38%, i.e., around 53 million tons. This means that around 15,960GWh are released unused into the environment during the production of electric steel! This is the output of two standard 1GW power plants.

In this article we would like to show how 2/3 of the lost energy*), i.e., approx. 200kWh/t_{LS}, can be saved in the process, i.e., that one ton of steel can be melted with approx. 500kWh/t_{LS} instead of an energy input of approx. 700kWh/t_{LS}.

*) Loss energy = exhaust gas, cooling water, slag, ohmic losses, radiation

Saving energy – let's consider two energy balances, the energy balance of a traditional electric arc furnace (EAF) and that of the eco-e two-chamber solution (eco-e tech):

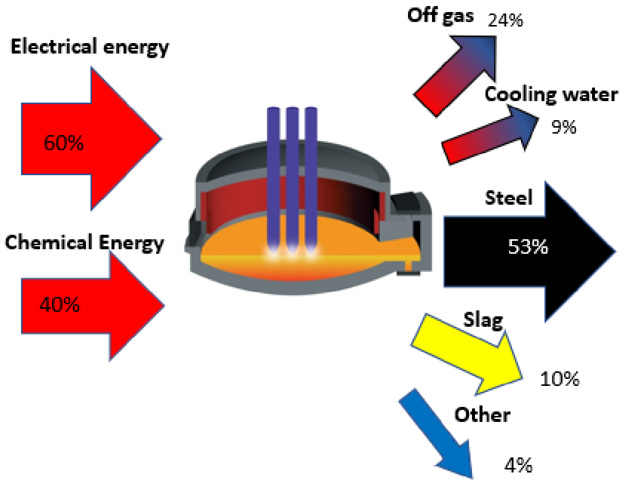


Figure 1 / Energy balance of a traditional electric arc furnace

Most of the exhaust gases in traditional electric arc furnaces are released into the atmosphere unused. The structure of the exhaust system usually consists of a water-cooled exhaust pipe, which leads the exhaust gas to a post-combustion chamber (PCC). In the PCC, the CO burns in conjunction with the atmospheric oxygen to CO_2. In the PCC, the coarse dust precipitates. After the PCC, the hot exhaust gas is cooled with fresh air or in a cooling tower to a temperature of about 200 °C. The exhaust gas then passes through a fine filter, where the residual dust is filtered out. Finally, the still warm exhaust gas is released into the environment via a high chimney. The energy efficiency is 53%.

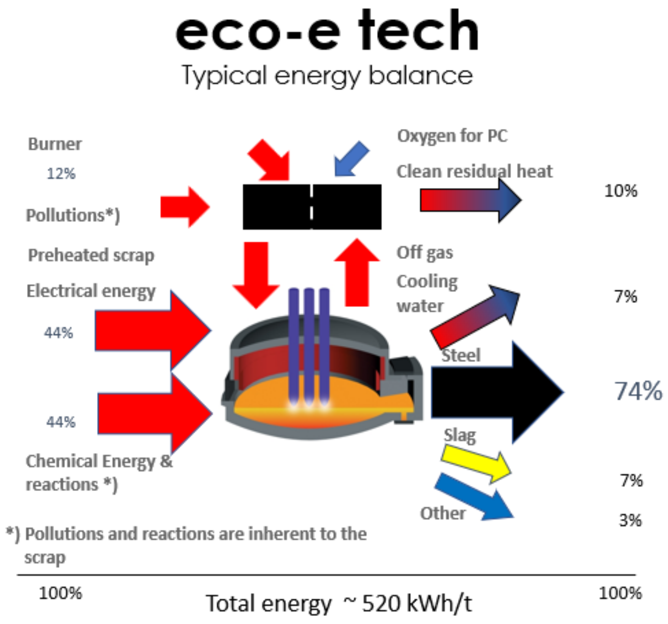


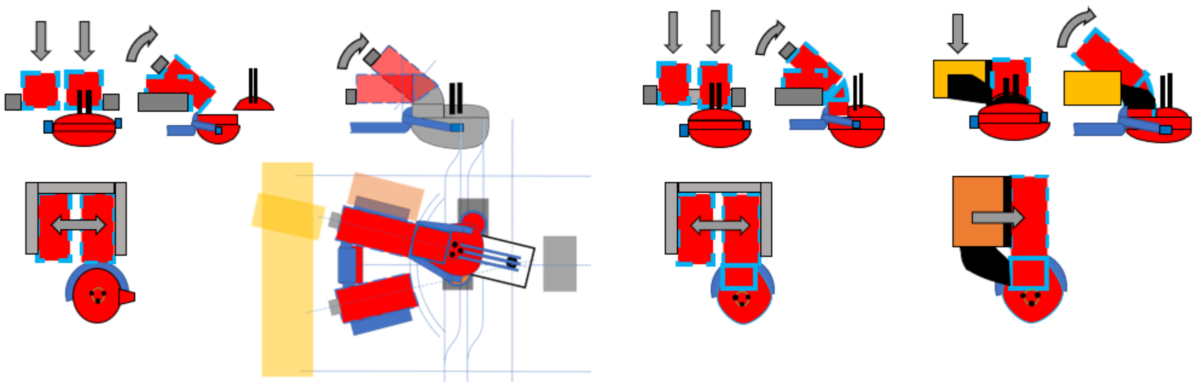
Figure 2 / Energy balance eco-e tech

Figure 2 shows the energy balance of eco-e's two-chamber solution. The energy efficiency here is 74% whereby the residual gas, which can still be used to its full extent at a temperature of approx. 600°C.

The advantage of the eco-e tech solution is that, on the one hand, the energy contained in the exhaust gas is transferred to the scrap to the maximum and, on the other hand, the residual gas energy, which can no longer be used for scrap preheating due to the heat transfer laws, is available as a clean, usable residual gas with a constant temperature[ii]. Another aspect is that all process-related energy inputs, such as the energy for combustion of hydro-chloride compounds and the post-combustion of CO, are used for scrap preheating. A decisive difference to conventional methods is the high degree of utilization of the energy introduced (approx. 74%, or 84% if the residual gas is used optimally). However, the climate neutrality required for 'GreenSteel' can only be achieved with a comprehensive measurement and control system that ideally controls all the variables. Yes, **GreenSteel** requires more than just intuition and gut feeling of the furnace operator – more on this in another article, 'Automation, the a and ω of the GreenSteel'.

Another difference to conventional methods is the process control in the furnace. The EAF has always been radiation but a convection furnace, i.e., a furnace in which the cold air is sucked to the fire and the consumed hot air escapes upwards. Like the fireplace of our ancestors, who did not succumb of suffocation in their caves thanks to this physical phenomenon. The furnace builders and possibly also the operators, who do not ask any questions, have apparently remained at this level. Thermally, however, this is not the yellow of the egg. With a simple, cost-effective conversion, the EAF can experience a true energetic miracle.[iii] The EAF becomes a furnace with internal scrap preheating and exhaust gas purification in one. The exhaust gas also experiences an energetic highlight. In the arc area, where a plasma prevails due to the high energy density, the highest temperatures prevail in the furnace. The hot exhaust gases, which rise upwards in the convection furnace and burn off the electrodes, are discharged laterally, flow through the smelting scrap and are sucked into the lateral exhaust duct, which surrounds half the furnace in the form of a torus. These exhaust gases are more energetic and less dusty.

The eco-e tech solution is used in the ECOFEEDER family.



ECOFEEDER E ECOFEEDER MF ECOFEEDER MC ECOFEEDER P

Figure 3 / The ECOFEEDER family

Here, a compilation of the advantages of the eco-e tech concept, divided into 5 groups:

1. **Direct energy-saving measures**, i.e., lower costs
   a) Higher preheating temperature of the scrap up to approx. 750°C (-130kWh/$_{\text{tFS}}$)
   b) Correct exhaust gas management in the furnace = better use of energy (-50kWh/$_{\text{tFS}}$)
   c) Integrated combustion of pollutants and use of combustion energy
   d) Integrated use of $CO \rightarrow CO_2$ post-combustion
   e) Integrated use of after-burners (combustion of dioxins/furans)
   f) Integrated furnace air preheating (~300°C) (-15kWh/$_{\text{tFS}}$)
   g) Constant residual gas temperature (~600°C)

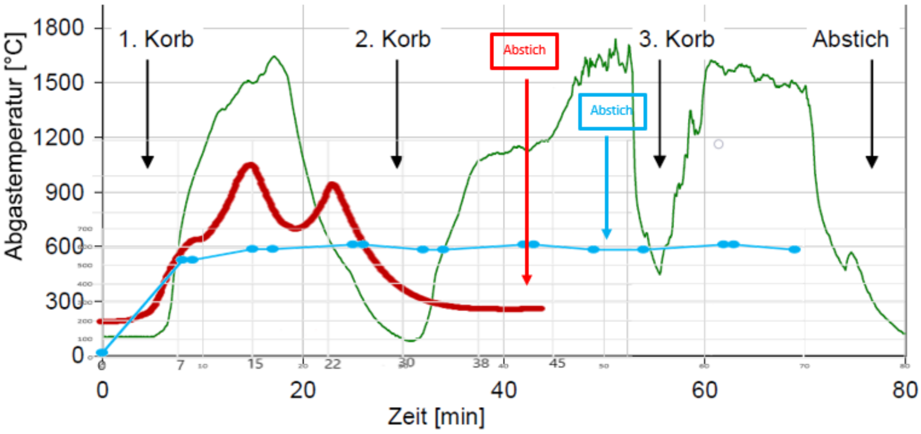


Figure 4 / Constant exhaust gas temperature of the ECOFEEDER© (blue line)

2. **Direct and indirect reduction of CO_2 emissions**, i.e., lower costs, less environmental impact
   a) Better burner utilization, thus fewer burners in use
   b) O-enriched furnace air with preheating (~300°C), thus less NOx
   c) Optimal exhaust gas management through automation
   d) Lower material consumption (slag formers/lining)
3. **Metallurgical advantages**, i.e., advantages that result qualitatively and quantitatively
   a) Value in use (VIU) analysis and optimization (DRI / scrap)
   b) Batch-neutral preheating (no mixing of scrap qualities)
   c) No scrap domes in the furnace, i.e., fewer bears
   d) Fewer electrode breaks
   e) DRI preheating and continuous DRI supply possible
4. **Maintenance advantages and flexibility gain**, i.e., lower costs
   a) Storage of preheated scrap in preheating containers possible
   b) Better access on the furnace roof (DRI supply) and to the electrodes
   c) Production during maintenance / repair possible
   d) No wear parts at exposed positions
5. **Commercial advantages**, i.e., better returns
   a) Lower electrode consumption (less side burn-up)
   b) Dust remains in the scrap → less waste
   c) Less mechanical wear of the lining
   d) Smaller furnace cooling capacity need (thanks to internal preheating and better formation of the foam slag)

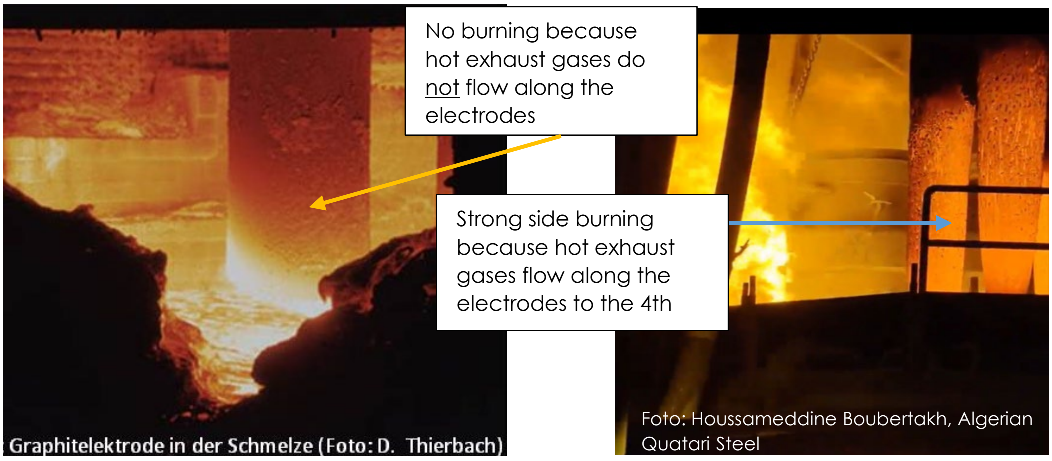


Figure 5 / Correct furnace air flow means less electrode burn-up

Well, as mentioned, a short business plan for the gradual conversion of an existing furnace. The advantage of this approach is that at no time a budget overdraft over the maximum investment amount will happen. Another advantage is that the certification of the existing furnace is retained, as none of the quality features are changed and the furnace can be operated as before.

Short business plan

Note: All information (effort) and figures (costs) are fictitious and non-binding.

Starting point: Electric arc furnace (EAF) (AC) (built in 1995), capacity 75t (hot heel 7t), transformer 70 MVA) with the following energy balance: Electrical energy input 415kWh/t_{LS}, gas (NG) 8.5Nm^3/t_{LS}, carbon dust 18kg/t_{LS}, Bulk carbon 0, electrode consumption 1.6kg/t_{LS} and 31Nm^3/t_{LS} oxygen (O_2) = net energy input 680kWh/t_{LS}, gross energy input (incl. reactions and pollutions) = 800kWh/t_{LS}.

The design of this EAF is traditional, i.e., round shape with tapping bay (EBT) and 2 wall burners, 1 door lance, 4th hole, cooling of roof and upper shell by pressurized water.

This EAF theoretically produces 136kWh/t_{LS} CO, i.e., unused bound energy and free energy of 170kWh/t_{LS} in the form of hot off gas. **That's 306kWh/t_{LS}, which are released unused into the environment.** The business goal is to optimize the melting process in such a way that as much energy as possible can be recycled or saved and at the same time CO_2 emissions can be reduced as much as possible.

Business Objective

Objective: Energy recirculation: 210kWh/t_{LS}, usable residual energy 60kWh/t_{LS}, i.e., reduction of the unusable residual energy emitted to the environment (slag, radiation, el. Losses, vascular cooling) to approx. 100kWh/t_{LS} in three steps, firstly thermal improvement of the furnace, secondly scrap preheating and exhaust gas treatment, thirdly optimization of furnace operation (VIU) by using DRI.

Interim goal 1: Reduction el. Energy input: 30kWh/t_{LS}, reduction electrode burn-up 0.5kg/t_{LS}, reduction chem. Energy input (burner insert) 20kWh/t_{LS} (CH_4 2Nm3/t_{LS}).

Interim goal 2: Reduction el. Energy input: 130kWh/t_{LS}, reduction of electrode burn-up 0.3kg/t_{LS}, use chem. Energy for exhaust gas treatment 40kWh/t_{LS} without CO_2 production (O-H burner)

Interim goal 3: Reduction el. Energy input: 50kWh/t_{LS}, reduction electrode burn-up 0.2kg/t_{LS}, reduction chem. Energy input (burner insert) 20kWh/t_{LS}

Total:	El. Energy input	-210 kWh/t_{LS}
	Electrode burn-up	-1.0 kg/t_{LS}
	Chem. Energy Input	-0.0 kWh/t_{LS}
	Reduction of CO_2 emissions	-40% (total approx. 150kg/t_{LS})
	(Usable residual energy	60 kWh/t_{LS})

Timeline Step 1:	Duration / Sum-up	
Project initialization (kickoff)	2 weeks	2 weeks
Basic Engineering	4 weeks	6 weeks
Detail Engineering	8 weeks	14 weeks
Fabrication (production) & transport	10 weeks	24 weeks
Pre-assembly & pre-commissioning	4 weeks	28 weeks
Production interruption, commissioning	2 weeks	32 weeks
Start of production (start up)	2 weeks	34 weeks

Timeline Step 2:	Duration / Sum-up	
Project initialization (kickoff)	2 weeks	2 weeks
Basic Engineering	6 weeks	8 weeks
Detail Engineering	10 weeks	18 weeks
Fabrication (production) & transport	16 weeks	34 weeks
Pre-assembly & pre-commissioning	6 weeks	40 weeks
Production interruption, commissioning	2 weeks	44 weeks
Start of production (start up)	4 weeks	48 weeks

Timeline Step 3:	Duration / Sum-up	
Project initialization (kickoff)	2 weeks	2 weeks
Basic Engineering	4 weeks	6 weeks
Detail Engineering	6 weeks	12 weeks
Fabrication (production) & transport	6 weeks	18 weeks
Pre-assembly & pre-commissioning	4 weeks	22 weeks
Production interruption, commissioning	2 weeks	24 weeks
Start of production (start up)	2 weeks	26 weeks

Cost Step 1:	
Engineering	500000.00 €
EPC (Engineering, Production, Commissioning)	1200000.00 €
Turnkey	2200000.00 €
Cost Step 2:	
Engineering	1600000.00 €
EPC (Engineering, Production, Commissioning)	5000000.00 €
Turnkey	8400000.00 €
Cost Step 3:	
Engineering	400000.00 €
EPC (Engineering, Production, Commissioning)	1000000.00 €
Turnkey	2000000.00 €

The savings and amortization calculation are based on the following, **fictitious** costs for electrical energy, natural gas, coal, electrodes, hydrogen, and oxygen.

El. Energy	100.00 €/MWh
Natural gas (NG)	40.00 €/MWh
Coal	120.00 €/t
Electrodes	15.00 €/kg
Hydrogen	10.00 €/MWh
Oxygen	0.10 €/Nm^3

Savings compared to the actual state:

Step 1:

(el. Energy 30kWh/t_{LS} * 0.1€/kWh + electrodes 0.5kg/t_{LS} * 15€/kg + natural gas 20kWh/ t_{LS} * 0.04€/kWh) 11.30 €/t_{LS}

Step 2:

(el. Energy 130kWh/t_{LS} * 0.1€/kWh + electrodes 0.3kg/t_{LS}* 15€/kg + add. consumption H2 -40kWh/t_{LS} * 0.01€/kWh) 17.10 €/t_{LS}

Step 3:

(el. Energy 50kWh/t_{LS} * 0.1€/kWh + electrode 0.2kg/$_{tFS}$ * 15€/kg + natural gas 20kWh/t_{LS} * 0.04€/kWh) 8.80 €/t_{LS}

Amortization:

Average weekly production (270000t/year / 50wo/year) 5400t/week

Average weekly savings and linear payback period:

Step 1:	61020.00 €/week
ROI (2200000€/61020€/week)	36 weeks
Step 2:	92340.00 €/week
ROI (8400000€/92340€/week)	90 weeks
Step 3:	47520.00 €/week
ROI (2000000€/47529€/week)	42 weeks

Cash-flow analysis:

In order to calculate the cash-flow, payment terms are a prerequisite. Let's use the following figures (ex. for a 'turnkey' contract):

Down payment when awarding the contract	15%
Partial payment on delivery BE	5%
Partial payment on delivery DE	15%
Partial payment on delivery (pro rata)	30%
Partial payment for readiness for installation (prior to production interruption)	25%
Final payment at FAC	10%

This results in the following picture:

The diagram below shows the individual steps (see above), their cash flow and their respective amortization, e.g., in step 1, the cash flow is maximum after about 34 weeks with -2108k€ and reaches the ROI (return on investment) after about 102 weeks. So almost 2 years after the start of the project. If you plan steps 1, 2 and 3 in such a way that the maximum cash flow does not exceed the granted investment, the return at the shortest possible ROI is maximized after about 218 weeks, i.e. after about 4 years. To this calculation would have to be added the possible increase in production, which can be fulfilled according to demand. This furnace could achieve an output of 100t/h and thus easily produce 600,000t/year.

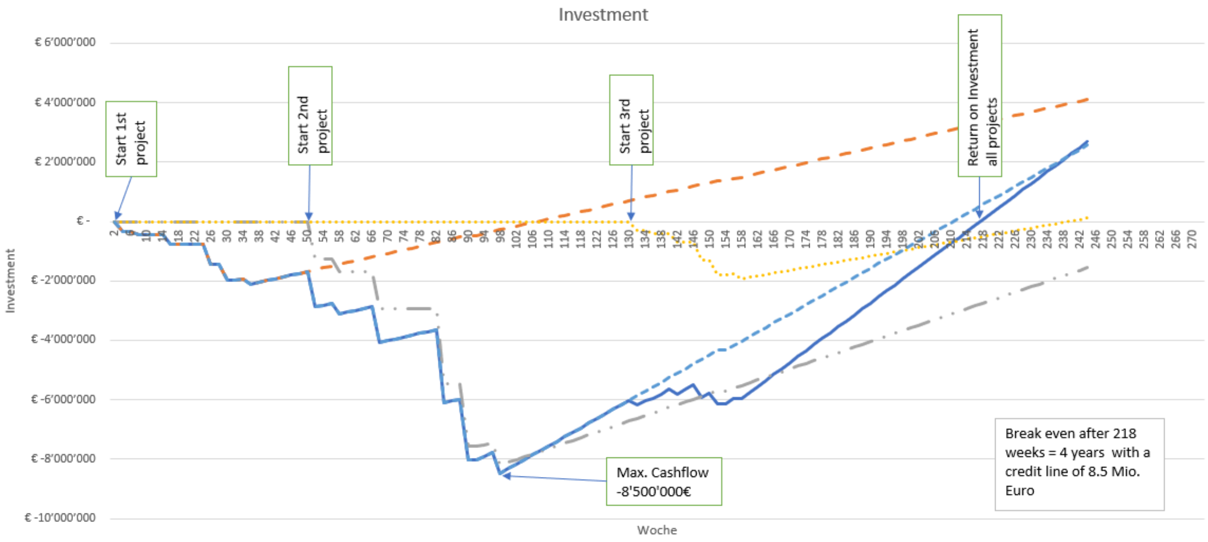


Figure 1 / Cashflow

Realization of a plant

In a first step, the furnace can be converted into a thermally efficient furnace as described with just a few changes. This enables initial savings. After successful commissioning and initial experience, an ECOFEEDER© E can be attached to the modified furnace. This conversion consists of three parts, which are pre-assembled in the workshop. The foundations for the roadway behind the furnace can be prepared during the maintenance shifts. The pre-commissioning and programming of the ECOFEEDER© E is carried out in the workshop, so that the actual commissioning on the construction site can be carried out very quickly. After the start of production, the system is optimized and prepared for continuous operation. As soon as the production has established itself at the desired level, the 3rd step can be tackled. The third step, the integration of continuous DRI conveying, can be realized with or without DRI preheating. The preparations and pre-commissioning take place again in the workshop. The actual commissioning of the 3rd step takes place during production.

Depending on your wishes, the ECOFEEDER© E can be converted into an ECOFEEDER© MC at a later date. For this purpose, adaptation of the lower and upper shell, possibly the platform and the furnace roof are necessary. The filling shaft is built with a special scaffolding. The ECOFEEDER© E does not have to be significantly rebuilt for this. This modification, in turn, can be prepared in such a way that production is only marginally impaired. The furnace conversion can be carried out in a few weeks.

DRI as scrap additive/replacement

Optionally, a continuous DRI conveying can be installed on the furnace instead of the 4th hole.[iv] As a consequence, however, combination burners (burners & O-lance combinations) would have to be used instead of the pure oxy burners (O-H or O-CH4). The DRI can thus be optimally preheated and melted down. Whichever DRI used, low %C or 0%C DRI, **GreenSteel** will be climate neutral – there is no net zero for steel!

Thanks to the utility value analysis, an optimal operating model can be established in which the proportion of DRI/scrap can be ideally adjusted.

Conclusion: The eco-e tech concept allows an existing production facility with poor exhaust gas utilization to be gradually converted into an efficient plant that can achieve the goal of 'climate neutrality' well before the deadline and is commercially profitable.

The concept also sets new standards for a new building in terms of efficient exhaust gas use and, accordingly, the lowest production costs.

On request, we will prepare a fee-based feasibility study, which will be fully credited to an eventual order. The feasibility study includes the analysis of the stock, a proposal based on the stock and a proposal for a complete or partial renewal of the scrap and smelting area, each with a detailed offer. Order a feasibility study today so you know where the journey is going with regard to 'GreenSteel'.

March 2022, Roland V. Müller, eco-e AG (www.eco-eag.com)

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[i] AIST Vol. 18 No. 3, page 7

[ii] 'The energy (pr)icebreaker', www.eco-eag.com/english/download, eco-e AG, 2022

[iii] 'EAF off gas – gain or loss? ', www.eco-eag.com/english/download, eco-e AG, 2022

[iv] 'DRI – Future of the Steel Industry?', www.eco-eag.com/english/download, eco-e AG, 2022