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The impact of scrap upgrading on EAF production cost and environmental performance

Qualitätsverbesserung des Schrotts beeinflusst Produktionskosten und Nachhaltigkeit des Elektrolichtbogenofens

Rutger Gyllenram and Olle Westerberg

Optimal operation in an EAF is not the same thing as buying the cheapest possible scrap. The amount of slag caused by the scrap affects the raw material cost, energy use and productivity. This makes scrap with a high oxide content costly. Uncertain analysis makes it difficult to control the content of tramp elements and forces the steelmaker to dilute the charge with expensive scrap from virgin steel production. With a value-in-use approach the potential for upgrading scrap to a higher quality grade can be calculated.

Beim optimalen Betrieb eines Elektrolichtbogenofens geht es nicht nur um den Einsatz von möglichst billigem Schrott. Der Schrott beeinflusst die Schlackenmenge und wirkt sich auf die Rohstoffkosten, den Energieverbrauch und die Produktivität aus. Aus diesem Grund wird der Einsatz von Schrott mit einem erhöhten Gehalt von oxidischem Material teuer. Unsicherheiten in der Materialanalyse erschweren die Begrenzung unerwünschter Begleitelemente und zwingen die Stahlhersteller, die Schrottcharge mit teurem „sauberen“ Schrott zu verdünnen. Mithilfe einer Kosten-Nutzung-Bewertung lässt sich das Potenzial für die Verbesserung der Schrotteigenschaften auf ein höheres Qualitätsniveau berechnen.

Photos: T. Aldenhoff, German Steel Federation

The option of using different scrap grades is an important strategy for the process of cost-effective steelmaking

Die Möglichkeit der Verwendung verschiedener Schrottsorten ist eine wichtige Strategie für eine kostengünstige Stahlerzeugung

Scrap, pig iron, HBI and alloys often represent more than 80 % of the production cost in EAF steelmaking. Scrap is classified and priced according to different standardized classes and other materials based on the content of the most important elements. However, the composition and physical properties of the individual material may vary within a class resulting in varying performance in the furnace. With better materials, and better knowledge of the actual quality of a material, steelmaking costs can be reduced. With scrap upgrading, oxides and steriles can be removed as well as other metals and alloys.

Cost factor	Amount	Unit
Availability	95	%
Fixed costs per year	20	million €
Capital investment	340	million €
Interest rate	15	%
Depreciation time	10	Year
Capital cost per year	73.8	million €
Additional cost per t steel	4	€
Slag handling fee per t slag	20	€
Dust handling fee per t dust	40	€

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Capital and other costs. The data are examples collected from industrial furnaces [1]

Kapital- und andere Kosten. Die Beispieldaten wurden an industriellen Lichtbogenöfen gesammelt [1]

Parameter	Amount	Unit
Furnace burners	5 000	kWh/charge
Oxygen for slag foaming	3 000	m^3 (S.T.P.)/charge
Electrode consumption	4.38	kg/MWh
Process water	10	m^3 (S.T.P.)/min
Tapping temperature	1 600	°C
Tap weight	100	t
Average power-on	50	MW
Average power idling	5	MW
Average idle time	5	min
Average power-off time	4	min
Power-on heat loss	5	MW
Idle/Power-off heat loss	1	MW
Post combustion	6	% in furnace
Dust from lime in EAF	1	%
Dust from metals in EAF	1	%

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Production parameters. The data are examples collected from industrial furnaces

Produktionsparameter. Die Beispieldaten wurden an industriellen Lichtbogenöfen gesammelt

With a better sorting or by using methods for analysis, a better or more narrow scrap analysis can be determined. This in turn makes it possible to have a more accurate charge calculation resulting in the opportunity to buy cheaper scrap or utilizing alloys in scrap better. The factors influenced are productivity, energy use, slag formers, slag amount, dust generation and tramp elements. These factors are also important for the environmental performance of the operation. This paper investigates the possibilities to upgrade, and to get better knowledge of the scrap. Finally the value in use of different grades within a scrap class is determined in order to estimate the potential to invest in upgrading.

Oxides, in for example skulls from ladles and tundishes, together with dirt are often included in the concept steriles and are common in scrap-based metallurgy. Tramp elements are unwanted alloy elements that occur in scrap. They may have many different origins, but some main sources can usually be identified. Copper is used in bearings and electrical wire and is often found in scrap. In scrap that comes from recycled steel the copper content in the steel matrix is often higher than in scrap that comes from blast furnace steel. Most steels are sensitive to the copper content. Thus, in many plants it is the only element considered in charge optimization. Other examples of elements that occurs like tramp elements are nickel and chromium coming from ferritic alloyed steel scrap; and tin and lead which often come from different kinds of coatings and bearings [1].

For a steelmaker it is important to know the analysis and composition uncertainty of the scrap in order to avoid getting too much of a tramp element into the steel. A steel charge normally consists of about ten different scrap types, which are blended to give the right analysis and smelting properties at the lowest possible cost. When the demands on limitation of tramp elements are high, scrap sources with a known analysis must be used. This can be new scrap from known sources or virgin material from the blast furnace route or Direct Reduced Iron (DRI).

Method

In order to investigate the value of clean, metallic scrap with a known analysis the optimization tool Rawmatmix [2] was used for three different cases:

- ▷ Use of crusts and upgraded crusts.
- ▷ Use of scrap with different amounts of dirt.
- ▷ Use of scrap with different variations in tramp elements.

In addition the carbon footprint of the three cases was assessed, taking into account emissions from the process itself as well as from preceding steps.

Calculations are made with an optimal slag practice with MgO saturated slag and an average 35 % FeO [3].

Capital and other costs used in the examples are shown in figure 1 and a number of production parameters used in the calculations are shown in figure 2.

The data used for raw materials is shown in figure 3. Important to note are the Cu-content and the Fe_{tot} values. Other raw material data is shown in figure 4.

Value of reducing FeO in crusts

Crusts and other residues are considered cheap or even free material and often favoured by the procurement department. In this case we shall look at the cost of using crusts and how that cost changes if we are able to upgrade the crust by removing a percentage of the oxide. The first calculation shows a charge with 100 % virgin scrap. The second a charge with virgin scrap plus 10 t of 50-% FeO skulls. In the third calculation the FeO content has been decreased to 10 % and the amount to 5.556 t.

The results shown in figure 5 indicate that the saving in material cost is more than outweighed by increases in energy and production costs when adding 50-% FeO crust to a charge. The increased energy cost comes from the fact that the oxides require more energy to melt and the production cost goes up because of increased tap-to-tap times and increased use of inject carbon for reduction.

The conclusion is that even if the oxidic material is provided free of charge it is not reasonable to use from a profitability point of view.

If the crust material can be upgraded to a 10-% FeO content the total cost of production will be lowered but the cost saving is not very large and will probably be cancelled out by the cost of upgrading.

Value of reducing SiO_2 in scrap

Sand and clay often contaminate the scrap being loaded into the furnace along with it. Some scrap yards in steel plants do not have hardened surfaces which will increase the Si content in the slag but some silicon could also emanate from the scrap recycling operators. This simple example shows the difference in energy and production cost if up to 1 % SiO_2 is present in the scrap.

The results in figure 6 show a cost increase of over 1500 € per 100 t charge and a doubled slag amount. The more SiO_2 there is in the scrap the higher the cost and this shows that there are strong reasons for having a tidy scrap yard and to remove gravel and other contaminations from your scrap.

Dealing with tramp element uncertainty

Scrap variation. Due to a variety of reasons the actual concentration of tramp elements in a scrap sample will vary. Given the volumes involved the actually measured concentration can be assumed to be normally distributed. A normal distribution is characterized by two values, a mean and a standard deviation. Figure 7 shows an example of the distribution of Cu in a scrap where the mean is 0.3 %. The figure shows the normal distributions for standard deviations ranging from 0 (no uncertainty) to 0.1.

Variations in analysis for the same product. The variation in analysis for the same product can be due

	High SiO_2 „Dirty“	High FeO Skull	Low FeO Skull	High Cu „Bad“	Virgin scrap „Good“
Fe	97.357	48.357	88.357	98.072	98.357
C	0.5	0.5	0.5	0.5	0.5
Si	0.3	0.3	0.3	0.3	0.3
Mn	0.8	0.8	0.8	0.8	0.8
Cu avg stdev	0.015 0.000 Known	0.015 0.000 Known	0.015 0.000 Known	0.300 0.030 Unknown	0.015 0.000 Known
FeO	0.0	50.0	10.0	0.0	0.0
$Si0_2$	1.0	0.0	0.0	0.0	0.0
Other	0.028	0.028	0.028	0.028	0.028
€/t Case 1 Case 2 Case 3	 – 0 –	 0 – –	 0 – –	 – – 240	 300 0 300

3

Raw material properties | *Rohstoffeigenschaften*

Raw material	Price * (€)	co_2** (kg CO_2-eq)	Ref upstream CO_2
Burnt lime (kg)	0.12	1.3	100% CaO
Burnt dolomite (kg)	0.15	1.3	30% MgO
Magnesite bricks (kg)	1	2.4	43 MJ/kg
Inject carbon (kg)	1	0.25	1 MJ/kg
Electrodes (kg)	4	1.5	27 MJ/kg
LPG incl oxygen (GJ)	20	25	55 m^3 (S.T.P.) O_2/GJ
Electricity (kWh)	0.15	0.819	Coal based
Oxygen (m^3 (S.T.P.))	0.1	0.393	ASU 0.48 MWh/ 1 000 m^3 (S.T.P.) electr
Process water (m^3)	0.1		Included in plant el.
CO_2 data for process emission and upstream calculation			
Natural gas	55 kg CO_2/GJ		
LPG	66 kg CO_2/GJ		
Inject carbon	3.7 kg CO_2/kg		
Electrodes	3.7 kg CO_2/kg		

* Prices are average prices from 2014 [1].

** Upstream CO_2 are examples of or estimations for typical production facilities. Large variations may occur. Energy source is natural gas unless otherwise stated [1; 4; 5].

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Other raw material and energy data | *Andere Rohstoff- und Energiedaten* to a number of reasons. Even if you produce the same end product there will still be significant variation between charges. Apart from the variation in raw material composition discussed above, such diverse factors as different recipes, precision of scales used, size and shape of the raw material and human error will contribute to the variation.

Figure 8 shows actual measurements of the variation in copper content for seven different products at one steel producer. We can see that one product has a very low Cu content with small variation; the majority of products have a slightly higher Cu level and variation while two products have Cu content and variation above the rest.

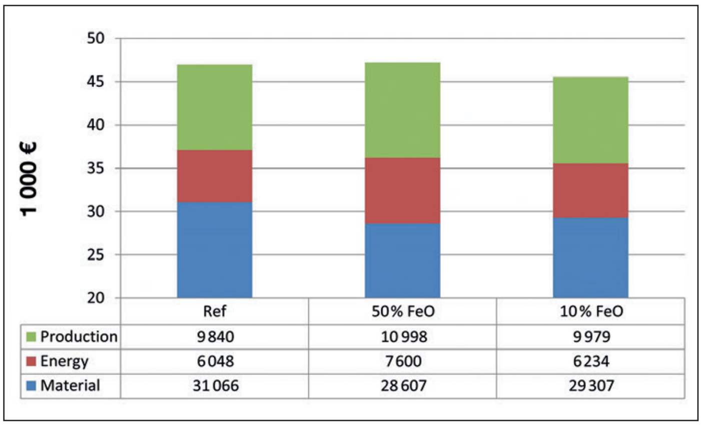
Data from actual charges can be used to calculate a predicted concentration of tramp elements like copper. The actual concentration for each charge can then be compared against this predicted value. The differences between actual values for charges and the predicted value will form a distribution like the one shown below in figure 9.

The figure shows a distribution that is the result of a weighted sum of the distributions of the materials. Because high concentrations in one material may be counteracted by low concentrations in another the resulting distribution for the product will be narrower than for the individual materials, i. e. the mere fact that several materials are mixed will help lower the variation.

The standard deviation of that tramp element in the product can be calculated according to equation 1:

$$Sdev_{mix} = \sqrt{X_a \cdot Sdev_a^2 + X_b \cdot Sdev_b^2 + \ldots + X_n \cdot Sdev_n^2}, \qquad (1)$$

where $a, b, \ldots, n$ are the different materials used for the charge. This means that if we know the variation



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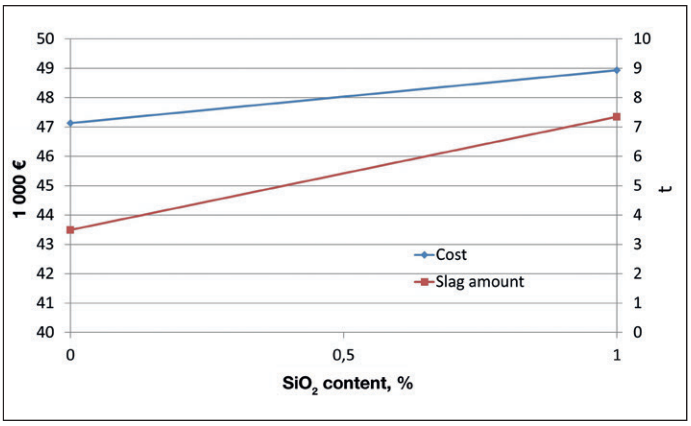
Cost of producing 100 t steel using skulls with varying FeO content

Kosten für die Herstellung von 100 t Stahl bei Verwendung von Bären mit unterschiedlichem FeO-Gehalt



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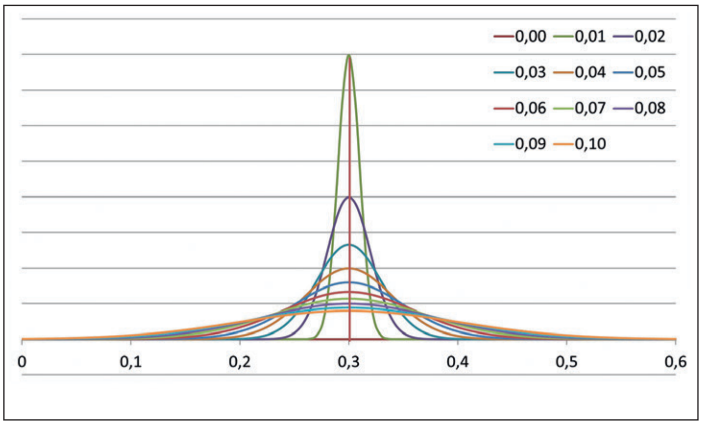
The effect on total cost and on slag amount by a 0 – 1 % SiO_2 content in scrap

Die Wirkung auf die Gesamtkosten und die Schlackenmenge bei einem SiO_2-Gehalt von 0 – 1 % im Schrott



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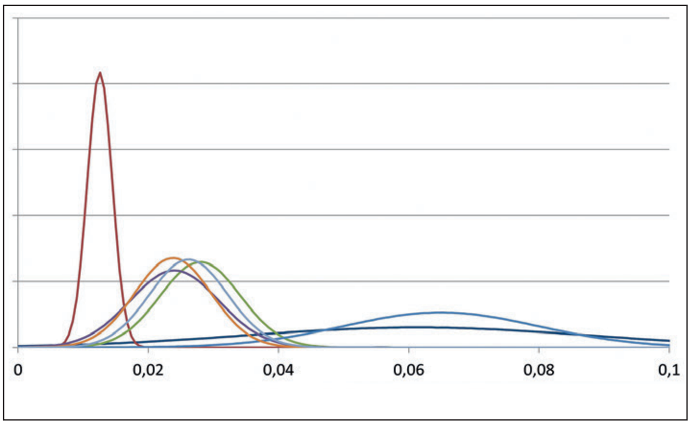
Distribution of Cu for scrap with standard deviations ranging from 0 to 0.1

Cu-Verteilung für Schrott mit Standardabweichungen im Bereich von 0 bis 0,1



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Variation in Cu analysis for seven different steel products. Sample taken after melting [6]

Schwankungen in der Cu-Analyse für sieben verschiedene Stahlprodukte. Die Probenahme erfolgte nach dem Schmelzvorgang in the content of the materials the variation in the resulting product can be calculated. This further highlights the benefit of knowing the analysis of your materials.

Assume that we have two materials, one with a low Cu content of 0.01 % with a very small variation and one with more Cu, on average 0.3 %, with a higher variation. Let us call the two materials "good scrap" and "bad scrap" respectively.

We mix these two materials together so that the averages meet the criteria for the product being produced, in this case a copper content of 0.1 %. The resulting copper content is described by the weighted average of the copper content of the two materials as shown in equation 2:

$$0.1 = X_{\text{good}} \cdot 0.01 + \left(1 - X_{\text{good}}\right) \cdot 0.3. \qquad (2)$$

In this example the result is that the required mix should use 69 % good scrap and 31 % bad scrap.

Figure 10 illustrates the distribution in the example above with only two materials. In a real world case with several materials involved the picture gets more complex.

The greater the variation in tramp element content, i. e. the greater the uncertainty for a specific material is, the more costly it is going to be to produce the desired product. When the uncertainty in the material grows higher the amount of that material that can be utilized in the production goes down.

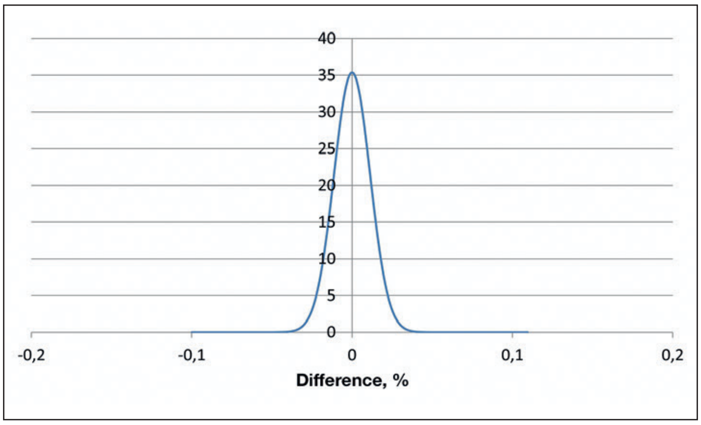
Figure 11 shows how the total cost varies with differing standard deviation for "bad scrap". As the standard deviation increases the proportion of "bad scrap" that can be used goes down and it has to be replaced by the more expensive "good scrap". In this example the difference between knowing that the standard deviation is 0.03 % (A) and having to assume the worst, e. g. a standard deviation of 0.09 % (B) is approximately 18 €/t scrap.

Optimal certainty factor in low alloy steel

What is then an optimal level of certainty? That depends on the cost of certainty and the cost of failed charges.

What can go wrong and what does it cost? The risks we are talking about here are for example that there will be too much of a tramp element in the end product or that there will be too little of a value element. Figure 12 gives estimates of the quality costs for different types of remedial action. If possible the customer agreement can be renegotiated or the failed product used for another customer through re-planning. In these cases the quality costs will be moderate. However, risks are great that this will not be possible and that you need to dilute the charge or scrap the charge altogether. Quality costs in these cases will be significantly higher.

Through the use of the normal distribution for the tramp element concentration in the product a confidence interval can be calculated and the quality costs above used to estimate the quality costs at different levels of certainty. For example a 95-% confidence in this case means that there is a 95-% chance that the value will be within the acceptable limits. In the case of tramp elements we do not care if the content is very low but are only concerned that the tramp element concentration should not exceed the maximum.



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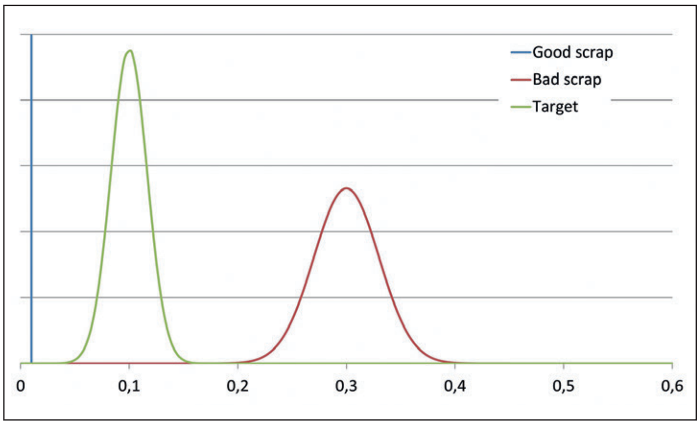
Standard deviation in Cu for a product where the predicted value is subtracted from the actual values of individual charges [6]

Standardabweichung für Cu für ein Produkt, wenn der vorhergesagte Wert von den tatsächlichen Werten der einzelnen Chargen abgezogen wird



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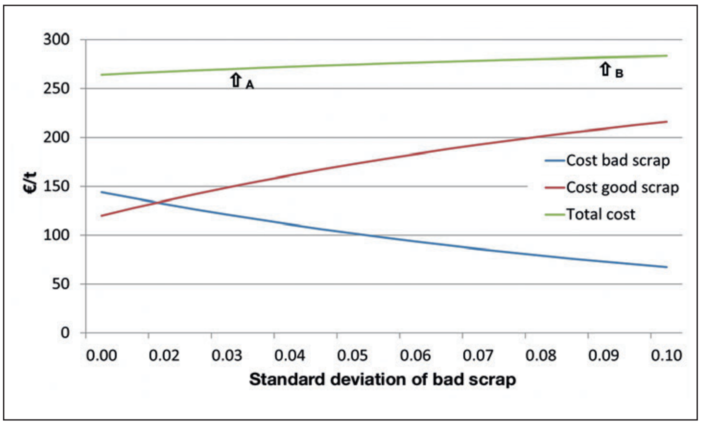
Distribution of Cu for "good scrap", "bad scrap" and a product produced from the two

Cu-Verteilung für „guten Schrott", „schlechten Schrott" und ein Mischprodukt aus beiden Sorten



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Production cost for an optimal charge for different degrees of variation in "bad scrap"

Herstellungskosten für eine optimale Charge in Abhängigkeit der Standardabweichung des „schlechten Schrotts"

Action	Quality cost, €/t
Re-negotiation	~1 — ~10
Re-planning	~1 — ~10
Dilution of charge	~10 — ~100
Scrapping of charge	~100 — ~1 000

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Estimated quality costs of different remedial action

Geschätzte Qualitätskosten verschiedener Abhilfemaßnahmen

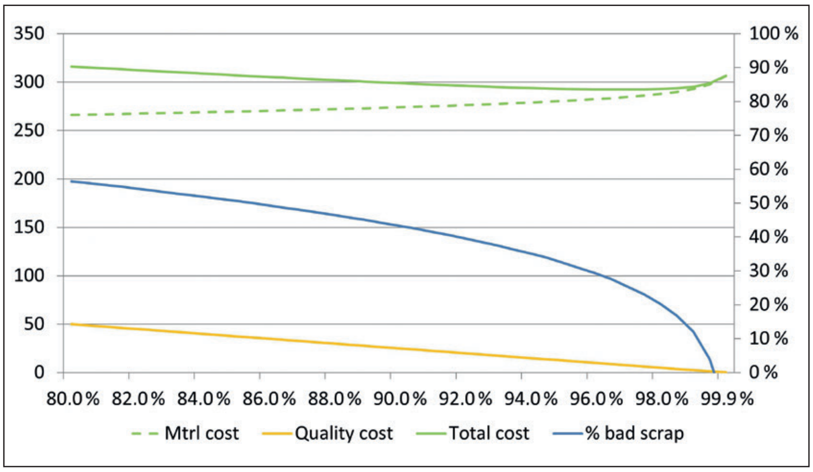
In the example shown in Figure 13 a quality cost of 250 €/t has been used. For this level an optimal level of confidence can be determined to be around 98 %. This means that we should load our charges so that there is approximately a 2-% risk, according to the laws of the normal distribution, that the level of tramp elements in the product will exceed the maximum level allowed.

Carbon footprint impact

Using the calculation tool Rawmatmix the total emission of greenhouse gases or carbon footprint for the production of a steel product can be calculated. There are two main sources of CO_2 emissions in steelmaking. Firstly, the CO_2 emitted during production and secondly the emissions created when producing raw materials, including energy and alloying elements. Figure 14 summarizes the carbon footprint for the four cases described in the cases a) and b) described above.

Upstream CO_2 is the carbon footprint of raw materials before entering into the melting process we are discussing here. Process CO_2 is the carbon footprint generated during this process, mainly from the inject carbon used.

The reason why upstream carbon footprint increases for scrap with high oxidic content is because you need more material as these materials will form more slag. The amount of the material itself, as well as slag formers and inject carbon for reduction, need to increase. It can be noted that the refined crust with only 10 % FeO has only marginally higher carbon footprint than the reference case. However, work will be required for the purification process which will generate emissions. This has only been partly taken into account here so the carbon footprint in this case is probably underestimated.



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Total cost, including quality costs at different levels of confidence

Gesamtkosten einschließlich der Qualitätskosten auf verschiedenen Ebenen des Vertrauensintervalls

(kg CO_2-equiv / 100-t charge)	Reference	50 % FeO	10 % FeO	1 % SiO_2
Upstream CO_2	27 364	31 342	27 845	30 317
Process CO_2	7 135	7 881	7 138	7 168
Total	34 499	39 223	34 983	37 485

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Carbon footprint of the steel produced in cases a) and b) in this paper

CO_2-Bilanz der produzierten Stähle in den Beispielen a) und b) in diesem Beitrag

Conclusion

This paper has shown that it is indeed possible to make calculations on optimal cost and carbon footprint for scrap-based steelmaking. The study shows that there are significant savings to be made through upgrading and better control of scrap. Finally, the importance of making proper value in use calculations have been highlighted showing that taking a simple purchase cost view on materials can lead to the wrong decisions being made.

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Rutger Gyllenram (Dr Eng), Chairman; Olle Westerberg (MSc, MBA), CEO, Kobolde & Partners AB, Stockholm, Sweden.

olle.westerberg@kobolde.se

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