# Taking in house and up stream $CO_2$ emission into account in charge optimization for scrap based steel making

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The scrap and ferroalloy purchases are by far the biggest costs for scrap based steel making. In search for lower prices, merchant steel producers tend to increase the amount of low grade scrap thereby increasing $CO_2$ emissions and energy use and decreasing productivity. For high alloy steel producers the profitability is often determined by the use of alloys in scrap since such alloys are discounted compared to ferroalloys. Costs for $CO_2$ emissions will probably go up in the decade to come, most probably increasing the prices for raw materials making decisions about the choice of raw materials even more critical.

For certain applications where different materials compete, like in the building sector, the importance of having a low total $CO_2$ load might be crucial due to new regulations like the Construction Product Regulation and standards for Life Cycle Assessment. With alloy production generating $CO_2$ emissions five to twenty times that of iron and scrap having no inherent $CO_2$ load the discount for scrap alloys might be questioned in the future provided the accuracy of the scrap analysis increases. These trends will most likely change the way the scrap market works.

This paper discusses optimal scrap charging and value in use for different raw materials assuming increased costs for in house $CO_2$ emissions and a wider interest in the total $CO_2$ load, i. e. including emissions for raw material and energy production, for certain product groups.

Calculations are performed with RAWMATMIX™, a free Internet tool for charge optimization, launched in Spring 2011, with energy and $CO_2$ calculations using average values and standard deviations for raw material data.

Different scenarios are assumed with different types of scrap, sources of electricity and allocation principles for environmental load. Data used has been supplied by Swedish steel makers and raw material suppliers. Scenarios show improved incentives for better scrap pre treatment as well as concern about the origin of electricity.

Keywords: Steel, Scrap, Optimization, Energy, $CO_2$, GHG, LCA, EPD

## Introduction

The focus on Global Warming and GHG emissions during the last decade is now materializing into standards, directives and new corporate market strategies. In the European construction sector a set of standards is emerging taking the GHG emissions in the building life cycle into account through CEN TC350[1]. This standard is intended to harmonize calculation rules and communication as is mentioned in the Construction Product Regulation, CPR, aiming at CE-labeling [2], and may influence certification programs like BREEAM [3]. On the global level the ISO TC209 SC7 is developing a standard for calculation and communication of a carbon footprint for a product [4]. Both these standard systems use LCA as a basic technology and Product Category Rules, PCRs as a basis for issuing Environmental Product Declarations, EPDs and refer to the ISO 14044 for LCA [5].

An LCA can be either consequential or attributional and this choice is of great importance to the outcome of a study [6]. In the consequential approach you assume that whatever you consume is on the margin production. That means for example that the consequence of using an extra kWh is the load from production of electricity from fossil fuels since this is the most expensive. For a steel plant the choice of supplier for ferroalloys would not necessarily matter from an environmental point of view since it might be difficult to argue that the margin production of the alloy has a higher environmental load. In the attributional LCA on the other hand the focus is on the actual environmental load generated in the production of a certain product. Here the choice of supplier of raw materials and resources is essential.

An EPD for a product can either be based on average data from several companies in an industrial sector or based on actual data from the actual producer of the product. The former is used in the steel industry where Worldsteel provides data to the LCA-databases. The latter might be used where the marketing value of a good environmental performance is of great importance like in the case of consumer products. The standards state that average data is acceptable for up stream production where data is hard to find but specific data is preferred.

Today the steel customers do not ask for corporate specific EPDs [7] but that will not necessarily be the case in the future. Steel producers are asked about the recycled content of the product and some customers ask for products made from 100% recycled steel. Another example of work in the supply chain is IKEA, the well known furniture company, which in the last years has invested in wind farms in France, Germany and Sweden. Apart from assuring a stable price of electricity, the company claims the investment is a part of its sustainability program for their stores [8] as they can now claim to be using renewable energy using actual data.

A final important issue relates to when more than one product leaves a production system and the environmental load might be allocated to both products according to some principle. Whereas the ISO 14044 prefers some physical principle like weight the CEN TC350 standards suggest economic allocation. In the case of blast furnace slag being used in concrete production this has become a sensitive matter since both the steel and the concrete industries want to improve the environmental properties of their main products by allocating some of the load elsewhere. Here it has even been suggested that the allocation method should be decided in a political process [9]. The same reasoning could be applied for new scrap by labeling it a product instead of waste relieving the main product of the environmental load of the scrapped material or at least part of it.

Environmental properties are already important issues in the marketing of building materials. Especially the choice between concrete, timber and steel has been discussed in numerous studies listed by Ortiz [10].

If specific data will be used for product declarations in the near future it is reasonable to believe that this will affect the choice of suppliers and the choice of raw materials as well as the process itself. The aim of this paper is to investigate possible ways to take in house and upstream $CO_2$ into account in charge optimization in electric steelmaking.

Charge optimization can be simplified as the process of:

- Procurement, taking the opportunities in the market into account for optimal total economic performance
- Blending to the right composition
- Meeting loading requirements
- Meeting process requirements
- Meeting market expectations on $CO_2$ abatement

In this paper we shall focus on the last bullet taking the first four into account. The work is performed as a parameter study with simplified data.

## Calculation model and choice of data

### *System*

RAWMATMIX™ is a web-based service for charge optimization available on www.rawmatmix.com consisting of a database with raw materials, steel products and example charge calculations. The system is a result from the research initiative Steel Eco Cycle at Jernkontoret, Sweden, and can be used for single or multi-charge optimization and calculation of statistic uncertainty in a charge. The optimization is done with multiple linear regression with restrictions on loading parameters, material groups and single materials.

The resources and raw materials used in this example are outlined in the following paragraphs. The $CO_2$ generated in house is subject to emission rights and reported as $CO_2$ Level 1. The $CO_2$ generated upstream is reported as $CO_2$ Level 2.

### *Energy and slag models*

For each charge of 100 ton in these calculations, 2000 kWh of LPG generating 0.25 kg $CO_2$ / kWh, is used and 1000 kg of inject carbon with 99.6 %C fix generating 3.7 kg $CO_2$ per kg and with necessary addition of oxygen to burn to $CO_2$.

| | Si | Mn | S | P | Cr | Ni | Cu |
|---|---|---|---|---|---|---|---|
| Carbon steel | 0.05 | 0.5 | 0.2 | 0.4 | 0.10 | 1.0 | 1.0 |
| Stainless steel | 0.05 | 0.8 | 1.0 | 1.0 | 0.97 | 1.0 | 1.0 |

*Table 1: Fraction of alloy elements going to steel based on a standard slag practice [11]*

| Transport means | kg $CO_2$/100 km/ton |
|---|---|
| Costal vessel | 1.4 |
| Rail | 2.3 |
| Tug | 2.7 |
| Heavy road transport | 9.2 |

*Table 2: Estimated $CO_2$ emissions from freight transport in EU15 [12]*

| Electricity source | kg $CO_2$ / MWh |
|---|---|
| Nuclear power [13] | 3.7 |
| Hydro power [13] | 6 |
| Wind power [13] | 17 |
| Coal combustion [13] | 819 |
| EU25 Grid Mix [14] | 539 |

*Table 3: $CO_2$ emissions from electricity production*

The energy efficiency is set to 85% for electricity and LPG and 100% for inject carbon. The electricity demand for the remaining energy need to reach a steel temperature of 1600℃ is thereafter calculated using different sources. 5 tons of slag and 5 tons of dolomite are added but their $CO_2$ emissions are not taken into account.

The model uses simple distribution factors shown in **Table 1** for alloys and tramp elements in the optimization calculation. Slag formers are added as fixed additions and if basicity is to be kept at a certain level or the slag amount affects the choice of material this change has to be done manually with iterative calculations. The system includes energy demand in the optimization by first calculating the cost for melting each material and adding that cost to the material price before optimization.

## Transport

For transportation of scrap to an electrical steel plant the flexibility of the road transport is balanced by the capacity and lower emission of the alternatives as shown in **Table 2**. Since companies in the recycling sector have the raw materials to produce bio-fuel this might become a way to improve the data for road transport. The advantage from a $CO_2$ point of view of a coastal location with railway connection is however clear.

## Electricity

The environmental load from electricity is often calculated as a grid mix for the region studied. However the origin may be taken into account with different strength in the argumentation ranging from

| Oxygen source | MWh/kNm³ | kg $CO_2$ / kNm³ Oxygen | | |
|---|---|---|---|---|
| | | Wind | EU25 | Coal |
| VPSA | 0.41 | 7 | 221 | 336 |
| ASU Plant | 0.48 | 8 | 258 | 393 |
| ASU Plant + liquid + road transport 100 km | 0.70 | 21 | 386 | 582 |

*Table 4: $CO_2$ emissions from oxygen making [16]*

| Material | Fe % | FeO % | C % | Si % | Mn % | S % | P % | Cr % | Ni % | Cu % | $CO_2$-Lev 2 kg/kg | Price € /kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base | 97.23 | 1 | 0.1 | 0.3 | 0.8 | 0.02 | 0.02 | 0.4 | 0.2 | 0.2 | 0.052 | 0.340 |
| New scrap | 97.65 | 0 | 0.1 | 0.3 | 0.8 | 0.01 | 0.01 | 0.2 | 0.1 | 0.1 | 2.052 | 0.360 |
| Residual | 88.23 | 10 | 0.1 | 0.3 | 0.8 | 0.02 | 0.02 | 0.4 | 0.2 | 0.2 | 0.052 | 0,308 |
| High P scrap | 97.17 | 1 | 0.1 | 0.3 | 0.8 | 0.02 | 0.08 | 0.4 | 0.2 | 0.2 | 0.052 | 0.340 |
| 18/8 -scrap | 73.57 | 0 | 0.1 | 0 | 0.1 | 0.015 | 0.015 | 18 | 8 | 0.2 | 0.052 | 3.2 |
| FeCr | 35.9 | | 0.1 | 3 | | | | 61 | | | 8 | 3.6 |
| Ni-cath | | | | | | | | | 100 | | 10 | 31.0 |

*Table 5: Raw material properties for the optimization cases. $CO_2$ for FeCr and Ni-cath [17]*

| Charging limits | | C | Si | Mn | S | P | Cr | Ni | Cu |
|---|---|---|---|---|---|---|---|---|---|
| Construction steel | Max | 0.1 | 0.1 | 0.8 | 0.015 | 0.015 | 0.3 | 0.3 | 0.3 |
| | Aim | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| | Min | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| Stainless steel | Max | 0.1 | 0.1 | 0.2 | 0.015 | 0.015 | 18 | 8 | 0.3 |
| | Aim | n.a. | n.a. | 0.1 | n.a. | n.a. | 18 | 8 | n.a. |
| | Min | n.a. | n.a. | 0.1 | n.a. | n.a. | 18 | 8 | n.a. |

*Table 6: Charging limits for the optimization*

an in house hydro electric power plant, ownership of wind parks to contracts for green electricity or supplier certification of origin [15]. The values vary as shown in **Table 3**. The huge difference between coal combustion and the other options might make electricity supply a top management priority in the decade to come. In the scenarios the value of wind power is used for green electricity.

### *Oxygen*

The $CO_2$ emission from oxygen is totally dependent on the source of electricity and whether the oxygen is produced on site or transported to the steelmaking site. There is only a slight difference in energy use between oxygen production with an ASU and a VPSA as shown in **Table 4**.

### *Scrap and other raw materials*

The raw materials used are displayed in **Table 5**. After the "end of waste" procedure the old scrap does not carry any burden other than an assumed 300km road transport to the plant. For new scrap this is perhaps not the case. A virgin steel producer or even a car producer using virgin steel might call the scrap "a product", allocate an appropriate portion of the load to this product and sell it to a scrap based plant. Hence the virgin steel producer might be inclined to buy old scrap in order to decrease the load for the virgin steel.

### *Produced qualities*

Finally the targets for charging into the EAF for a construction steel type and a standard stainless steel type are outlined in **Table 6**.

## Production cases

### Raw material and energy selection for construction steel production

The quality of scrap is of big importance to the economy of electric steelmaking For construction steel a simple set of calculations are outlined in **Table 7** with idealized scrap types for clarity. Two scrap types are studied: residual material with high FeO content and a scrap with high or varying content of a tramp element that demands dilution with new virgin scrap.

The $CO_2$ level 1 that emanates from burners and coal injection represents an amount of around 4.5 ton $CO_2$/charge resulting in a $CO_2$ trade cost of around 0.75 € /ton with today's prices and is therefore negligible in this comparison.

As a reference charge a standard base mix of old scrap like E3 and shredded material is used for 100 tons of construction steel (Base). This case is then modified by replacing part of the mix with 10 tons of a residual material with 10% FeO content still aiming at 100 tons of steel. In a first calculation (Res 1) the same efficiency of 85% of electricity use is assumed whereas in a second calculation (Res 2) an efficiency of 80% is assumed due to increased slag amount and energy use. The calculated $CO_2$-emissions differ by around 6% between these three cases. Since the price of the low grade scrap is proportional to the iron content and the same amount of slag formers is used the difference in production cost reflects the energy use only.

In a fourth calculation use of 30 tons of scrap with high or randomly varying phosphorus content (High P) illustrates the need for dilution in this case. The new virgin scrap has been allocated a load of 2 kg $CO_2$ per kg scrap and has been given a premium of 20€ to the base mix.

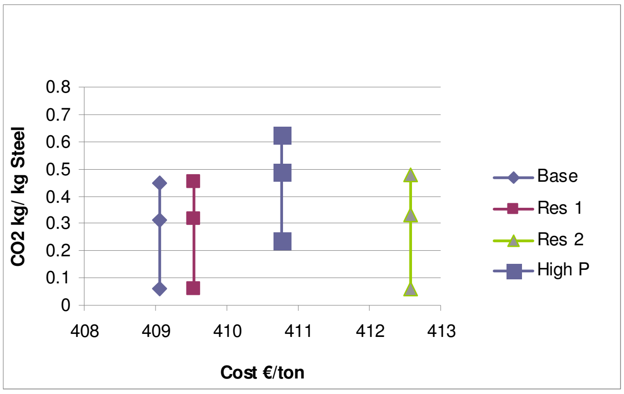


*Figure 1: $CO_2$ level 2 from scrap, electricity and oxygen for four different production cases for construction steel with three different sources of electricity.*

All four cases are calculated using electricity from wind power (WP), coal combustion (CC) or a European grid mix (EU25). In **Figure 1** it is clearly shown that the choice of electricity is of great importance and the difference in production cost can be used to calculate a value in use for the low grade materials indicating a further reduction of the price by 5-35€ for the residual and 6€ for the scrap with uncertain phosphorous analysis. This indicates that a further upgrade of the scrap should be possible and desirable from an environmental point of view.

## Raw material and energy selection for stainless steel production

For stainless production the main source of $CO_2$ level 2 is the addition of ferroalloys. In this parameter study for a standard 18/8 stainless steel the amount of low alloyed scrap is varied from 0 to 100% of the scrap charge. Low alloy scrap may be used either because of scrap shortage, uncertainty about the alloy content in the stainless scrap or of necessity to dilute one or more tramp elements. The calculations are outlined in **Table 8** and the results displayed in **Figure 2**.

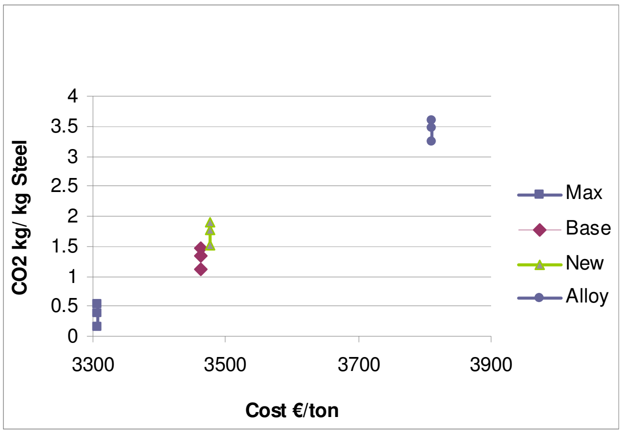


*Figure 2: $CO_2$ level 2 from scrap, electricity and oxygen for four different production cases for stainless steel with three different sources of electricity.*

In the first case (Max) the amount of stainless scrap is maximized resulting in the lowest production cost and level 2 $CO_2$ rate. In the next two calculations (Base) and (New) 20 tons of low alloy scrap is used and finally a case where almost all alloying elements come from ferroalloys resulting in the highest cost and level 2 $CO_2$ rate.

These calculations stress the importance of good scrap processing and alloy recovery in the recycling phase since it enables the steel plant to use less ferroalloys.

| Case | Data | Use of material | | | $CO_2$ Level 2 (kg/kg) | | | Cost € /ton |
|---|---|---|---|---|---|---|---|---|
| | | Base scrap | New scrap | Low grade | WP | EU25 | CC | |
| 1 | Base | 101850 | 0 | 0 | 0.061 | 0.313 | 0.449 | 409.06 |
| 2 | Res 1 | 92767 | 0 | 10000 | 0.062 | 0.316 | 0.453 | 409.53 |
| 3 | Res 2 | 92767 | 0 | 10000 | 0.062 | 0.333 | 0.478 | 412.58 |
| 4 | High P | 63156 | 8688 | 30000 | 0.235 | 0.487 | 0.622 | 410.76 |

*Table 7: Cost and $CO_2$ emissions from electric steelmaking of construction steel products depending on four raw material mixes and oxygen and electricity from wind power (WP), Gridmix (EU25) and coal combustion (CC).*

| Case | Data | Use of material | | | | | $CO_2$ Level 2 (kg/kg) | | | Cost € /ton |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 18-8 scrap | New Scrap | Base scrap | Cr | Ni | WP | EU25 | CC | |
| 1 | Max | 99511 | 0 | 0 | 1057 | 39 | 0.148 | 0.392 | 0.523 | 3306 |
| 2 | Base | 68561 | 0 | 20000 | 10059 | 2475 | 1.106 | 1.350 | 1.481 | 3463 |
| 3 | New | 68429 | 20000 | 0 | 10163 | 2506 | 1.518 | 1.761 | 1.892 | 3476 |
| 4 | Alloy | 0 | 0 | 64305 | 29999 | 7871 | 3.229 | 3.472 | 3.603 | 3810 |

*Table 8: Cost and $CO_2$ emissions from electric steelmaking of stainless steel products depending on four raw material mixes and oxygen and electricity from wind power (WP), Gridmix (EU25) and coal combustion (CC).*

## Conclusions

The literature data presented in this paper suggest multiple choices for transportation, electricity and oxygen which are provided for reference. There are obviously a lot of improvements to be made in operating a steel pant. In the end the most important result in this study is the difference between the high and low examples taking the major sources of $CO_2$ into account.

The calculations show that the $CO_2$ value for a low alloy steel might differ by 0.5 kg and for stainless steel by more than 3 kg per kg of steel depending on the choice of procedure. In order to understand if it is important we can study a steel intensive product like a building regardless of the actual origin of the steel used in this application. For the new construction Stockholm Waterfront shown in **Figure 3** with 25000 $m^2$ of office space and an additional 49000 $m^2$ for hotel and congress building, 2000 ton of low alloy steel and 65 of stainless steel has been used. This gives a span of 1227 tons of $CO_2$ for the amount of steel used using data from the cases.

The annual energy use from the office part which constitutes a third of the building is 1.5 MWh [18] representing 25 tons of $CO_2$ from wind power or 800 tons from EU25 Grid Mix which is in the same range or less than the calculated span.

The method and choice of data for these calculations can of cause be questioned since the marginal steel always is produced from virgin material. This is however not necessarily the issue here. In each purchasing situation the customer of goods or services might, for ethical or other reasons, want a product that is produced with a minimum of environmental effects regardless of marginal effects. For any company in such a supply chain it then becomes a necessity to make its EPDs competitive. The examples in this paper are therefore relevant. Whether it will be compliant with certification standards is yet to be discovered.

In competition with concrete, a steel EPD with very low GHG emissions due to old scrap, railway transports and low GHG electricity will come out very strong since concrete has most of its emissions from chemical reactions and fossil fuel. Different $CO_2$ loads for different suppliers of the same type of material will no doubt make it more difficult to publish general articles promoting any single one of these material groups. This fact might even benefit all steel producers.

Procurement in a market with raw materials with similar physical and chemical properties but different environmental properties might cause unnecessary transportation, corrupt reporting or other dysfunctionalities. Identifying these pitfalls will be an important task for researchers and market

*Figure 3: Stockholm Waterfront. A steel construction made from 2000 tons of construction steel and 65 tons of stainless steel. It has advanced energy solutions resulting in energy usage for heating and cooling of half the limit for a green building.[19]*

organizations in the future as the use of specific EPDs develop.

Finally it is the authors' opinion that the road to success is both real world actions like better scrap treatment, for example to reduce the amount of oxides or using scrap alloys better, and good procurement identifying good raw materials with low $CO_2$ burden.

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