Raw material assessment for electric arc furnace steelmaking

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Abstract: In this study, steelmaking in an Electric Arc Furnace, EAF, using two types of recycled scrap with different levels of tramp-Cu and different prices, is compared to steelmaking where part of the burden is changed to a virgin iron source. By using the tool RAWMATMIX® for optimizing EAF charges, a Value in Use, ViU, is calculated for Blast Furnace Hot metal, Pig Iron, Hot and Cold DRI and HBI. The result shows that the ViU per ton material differs from +57% to -39% for the different sources. Using virgin material also affects the environmental profile of the product and especially the Global Warming Potential, with different CO_2 burdens depending on source. The paper shows the importance of making ViU calculations when establishing a raw material price.

Key words: Electric arc furnace, Scrap, HBI, Hot Metal, Pig Iron, Tramp element, Global Warming Potential, Value in use

1. Background

Steel is a 100% recyclable material. Obsolete products together with new scrap coming from production, are collected, sorted and formatted to fit into different classes according to some classification system. Each class states the allowed geometry, density, thickness, levels of alloying elements or pickable metal parts, coatings, steriles, sources for the material etc. One example of a system for specifying the different classes is the EU-27 Steel Scrap Specification 2007 [1].

Tramp elements are unwanted alloys that occur in scrap. They may have many different origins, but usually some main sources can 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 cupper 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 [2].

For a steelmaker it is important to know the analysis and uncertainty of the scrap in order to avoid getting to 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 low levels 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 ore like Blast Furnace Iron or Direct Reduced Iron.

By using Life Cycle Analysis, LCA, the environmental load from primary production of steel from ore and secondary production of steel from scrap can be scrutinized. Although it is right to argue that there can be no scrap based steelmaking unless there has been a primary steelmaking first, it is important to understand how different sources changes the load. The way to report the impacts are given in a number of standards and for the Global Warming Potential an ISO technical specification also exist [3]. Using virgin material together with recycled material adds a twist to this question, which is discussed later in the paper.

2. Method

In this study we have chosen to set a market price to scrap of a premium and second quality and then estimate the Value in Use, ViU, for the virgin iron sources. E3 is a heavy old scrap with a Cu limit of 0.25% and E1 is a lighter scrap with a Cu limit of 0.4%, according to specifications [1]. Prices are average prices valid for year 2014 [4].The calculation base is 100 ton steel with a Cu-limit of 0.22%. In the reference charge we use 100 % scrap and in the virgin charges we use 60 ton scrap and 40 ton virgin material.

The steel is produced in a modern EAF with burners using Liquid Petrol Gas, LPG. We strive for a slag contains 20% FeO, 38% CaO as well as a 10% MgO oversaturation to reduce refractory wear. Also the same time for charging the different raw materials to the furnace is assumed.

The virgin materials are: hot metal, HM, from an adjacent blast furnace, pig iron, PI, which is a commodity that is traded globally, Hot DRI, HDRI, from an adjacent natural gas based shaft furnace, Cold DRI, CDRI, from the same furnace but perhaps transported some distance, and finally HBI which again is a globally traded commodity. The hot metal and pig iron have the analysis of a normal blast furnace iron which is low in Si. The DRI is a low-Si and high MgO containing DRI typical for the Gulf area and the USA. Finally, the HBI is a standard commercial grade. The software RAWMATMIX®

calculates the raw material mix that meets the product requirements at lowest possible cost. It uses the MgO saturation model presented by Selin [7] to calculate lowest possible amount of slag former addition to meet the slag requirements. Dust is calculated as a percentage of metals melted and a percentage of the fine fraction of the raw materials. This comparison is simplified in the way that it is assumed that no difference between carbon in the raw material and inject carbon exists. The added carbon from coal is first dissolved in the melt (22.5 kJ/mol), before it is oxidized.

When estimating the ViU for a material x the difference between the production cost for a reference case, C_{ref}, and the production cost for a case using material x, C'_x, is divided by the amount of material x, w_x. C'_x does not include the cost for x and the result will be the price for x that would result in the same production cost as the reference case everything else alike. It could be expressed as in equation 1.

$$ViU_x = \frac{C_{ref} - C'_x}{w_x} \quad [1]$$

The ViU may be higher or lower than the market price. Thus if it is higher you should buy and if it is lower you should avoid buying. It is evident that the ViU is strongly dependent on the reference case which should be representative for the normal practice you use for the steel product for which you consider to use the alternative material. Furthermore, the calculations are simplified and do not reflect real burdens. However, the method gives an opportunity to investigate the intrinsics of different materials and how they are priced.

The data for CO_2 emissions for upstream processes are based on the assumption that the production takes place where electricity is produced from coal in a modern plant and other raw materials with Natural Gas.

3. Calculation data

Capital and other costs are shown in Table 1 and a number of production parameters used in the calculations are shown in Table 2. For all prices and costs, the exchange rates 1 CNY = 0.137 EUR and 1 EUR = 7.3 CNY are used.

Table 1 Capital and other costs*

Cost factor	Amount	Unit
Availability	95	%
Fixed costs per year	20 / 146	MEUR / MCNY
Capital investment	340 / 2482	MEUR / MCNY
Interest rate	15	%
Depreciation time	10	Year
Capital cost per year	73,8 / 539	MEUR / MCNY
Additional cost per ton steel	4 / 29	EUR / CNY
Slag handling fee per ton slag	20 / 146	EUR / CNY
Dust handling fee per ton dust	40 / 292	EUR / CNY

* Cost factor data are examples collected from industrial furnaces [2]

Table 2 Production parameters*

Parameter	Amount	Unit
Furnace burners	5000	kWh/charge
Oxygen for slag foaming	3000	Nm^3/charge
Electrode consumption	4.38	kg/MWh
Process water	10	m^3/min
Tapping temperature	1600	˚C
Tap weight	100	ton
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 metallics in EAF	1	%

* Parameter data are examples collected from industrial furnaces

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

Table 3 Raw material properties

	E3	E1	HM	PI	DRI	HBI
Fe	95	94.3	95	94	84.57	82.74
C	0.4	0.4	4.2	4.2	2	2
Si	0.3	0.3	0.5	0.5		
Mn	0.8	0.8	0.2	0.2		
Cu	0,25	0.4	0	0		
FeO	2	2	0	1	9.46	9.24
CaO					1.1	0.93
MgO					0.35	0.23
SiO_2	0.5	1			1.48	4.55
Al_2O_3	0.5	0.5			0.56	0.24
Other	0.5	0.3	0.1	0.1	0.48	0.07
Fe_{tot}	96,56	95,86	95	94,78	91,95	89,95
Met					92%	92%
T (˚C)	25	25	1450	25	C: 25 H: 500	25
Price (EUR) [4]	264	240	-	-	-	-
Price (CNY)	1927	1752	-	-	-	-
Upstream CO_2 (kg CO_2eq) *	0	0	1.8	1.8	0,77	0.77

* CO2 values for HM and PI are based on average European Blast furnace data. Values for DRI and HBI are based on shaft furnace production using Natural Gas.

Table 4 Other raw material and energy data*

Raw material	Price * (EUR/CNY)	CO_2 ** (kg CO_2eq)	Ref upstream CO_2
Burnt Lime (kg)	0,12 / 0,88	1,96	100% CaO 8 MJ/kg
Burnt Dolomite (kg)	0,15 / 1,09	2,7	30% MgO 11 MJ/kg
Magnesite bricks (kg)	1 / 7,3	10,5	43 MJ/kg
Inject Carbon (kg)	1 /7,3	0,25	1 MJ/kg
Electrodes (kg)	4 / 29,2	6,6	27 MJ/kg
LPG incl O_2 (GJ)	20 / 146	25	55 Nm3 O2/GJ
Electricity (kWh)	0.15 / 1,09	0,819	Coal based
Oxygen (Nm^3)	0,1 / 0,73	0,393	ASU 0.48 MWh/kNm3 electr
Process water (m^3)	0,1 / 0,73	-	Included in plant el.
CO2 emission used for process emission and upstream calculation			
Natural Gas (GJ)	245 kg CO_2/GJ		
LPG (GJ)	291 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 [2].

** Upstream CO_2 are examples or estimations for typical production facilities. Large variations may occur. Energy source is Natural Gas unless other stated [2][5][6].

4. Calculation result

The optimized burden is shown in Table 5. The reference calculation, "Scrap", uses almost only the more expensive E3 as burden. The virgin materials that all lack Cu can use the less expensive E1. The slag formers show that the HBI charge needs more dolomite than the others to balance the high Si-content.

Table 5 Charged materials and injected coal

Charge	Scrap	HM	PI	HDRI	CDRI	HBI
E3	99.351	8.897	8.897	8.897	8.897	8.897
E1	5.876	51.103	51.103	51.103	51.103	51.103
Fe-alt		46,245	46,354	48,194	48,194	50,080
Lime	1.636	1.253	1.254	1.369	1.369	1.595
Dolo	2.033	2.099	2.101	2.239	2.239	4.392
Coal	2129	253	308	2122	2122	1930

In Table 6 and Fig. 1 the ViU for the virgin materials are shown together with the 2014 average European market price for E3. The highest competitive price for HM is 367 EUR. This is 39% over the price for E3 per ton of material and 41% over the price for E3 per ton of Fe. HDRI has a ViU similar to E3 whereas HBI has a ViU of 150 EUR. This is -43% less than the E3 material price and -39% less than the E3 price per ton of Fe.

Table 6 Value in use (ViU) in EUR (upper), CNY (lower) and relative difference to heavy old scrap E3

Charge	Scrap	HM	PI	HDRI	CDRI	HBI
ViU /ton	264	416	332	263	210	161
mtrl	1927	3033	2420	1918	1534	1179
Relative	**0**	**57**	**26**	**0**	**-20**	**-39**

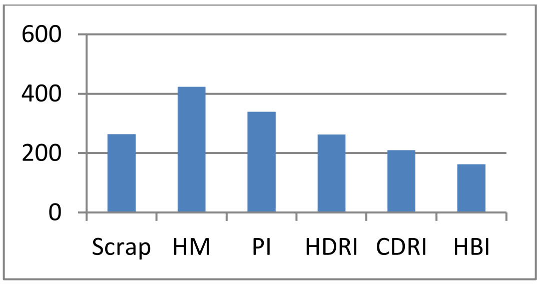

Fig. 1 Value in Use, ViU, in EUR, for virgin Fe-sources compared to heavy old scrap E3

Table 7 Production costs in EUR (upper) and CNY (lower) for a charge of 100 ton.

Charge	Scrap	HM	PI	HDRI	CDRI	HBI
Iron	27639	33830	29984	27280	24740	22700
mtrl*	201743	246935	218865	199124	180587	165691
Slag	502	466	467	501	501	851
former	3666	3404	3406	3658	3658	6214
Energy	8588	5137	6593	8709	9647	10118
	62689	37499	48125	63568	70418	73856
Other	2529	2032	2458	2589	2874	3165
op cost	18459	14835	17942	18900	20980	23103
Sum	39 258	41 466	39 502	39 079	37 763	36 834
op cost	286556	302673	288338	285250	275644	268863
Fixed	9355	7147	9111	9534	10850	11779
cost	68285	52168	66504	69591	79197	85978
Prod	48 613	48 613	48 613	48 613	48 613	48 613
cost	354841	354841	354841	354841	354841	354841

* Cost for iron material other than scrap is based on the calculated value in use.

In Table 7 and Fig. 2 the production cost for a charge of 100 ton is outlined. The ViU for the virgin iron materials are used, which means that the total production cost at the bottom line is the same for all alternatives.

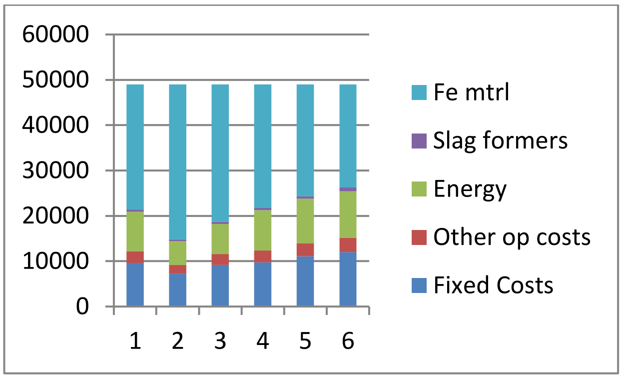

Fig. 2 Production costs in EUR for a charge of 100 ton using the ViU value as a price for virgin Fe-materials

Virgin materials like DRI and HBI normally contain higher Si and SiO_2 contents than scrap. As a result, more dolomite has to be added in order to create a slag that is not aggressive to the furnace lining. Table 5, Table 9 and Fig. 3 show some important slag figures that illustrate that lime decrease and dolomite increase. Overall, the most stunning result is the large amounts of slag shown in the HBI case.

Table 8 Productivity, dust and slag

Charge	Scrap	HM	PI	HDRI	CDRI	HBI
Tap to tap (min)	61.14	46.81	59.31	63.42	71.76	77.5
Dust (kg)	1398	1386	1386	1396	1396	1451
Slag (kg)	7985	7112	7116	9073	9073	13441
Slag MgO eq (%)	6.86	7.97	7.97	8.38	8.38	9.6
Slag SiO2 (%)	15.52	20.34	20.35	18.37	18.37	24.2

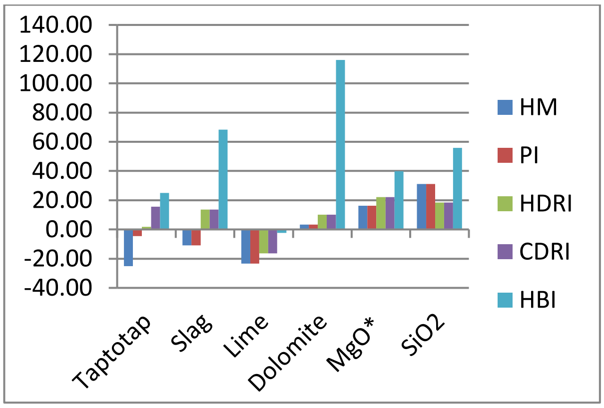

Fig. 3 Relative changes to the Scrap reference case regarding tap to tap time, lime and dolomite additions, slag volume and resulting MgO and SiO_2 analysis of the slag with 10% MgO oversaturation

Finally, it should be noted that when using virgin materials the environmental profile of a material changes. According to the standards for LCA and environmental declarations [3], a recycled material comes free of upstream environmental burden for the period before it reached the “end of waste” status. A virgin material must carry its environmental burden, but can declare a credit that it can be recycled and replace steel from virgin materials. However, it is important to understand the carbon metrics in order to appreciate the environmental declarations and to communicate the environmental performance. To escape the discussion about recycled and virgin materials the upstream CO_2 for Fe-materials is omitted in Fig. 4. The result is that the CO_2 differs between the alternatives due to different amounts of electricity, lime and dolomite.

Table 9 Global Warming Potential expressed as kg CO_2/kg steel.

Charge	Scrap	HM	PI	HDRI	CDRI	HBI
CO_2 Process	0.148	0.144	0.145	0.177	0.177	0.171
CO_2 Upstream	0.323	1.064	1.143	0.703	0.754	0.802
CO_2 Upstream*	0.322	0.232	0.309	0.332	0.383	0.416
CO_2 Total	0.471	1.208	1.288	0.880	0.931	0.973
CO_2 Total*	0.470	0.376	0.454	0.509	0.560	0.587

*** Upstream CO2 for Fe-materials left out**

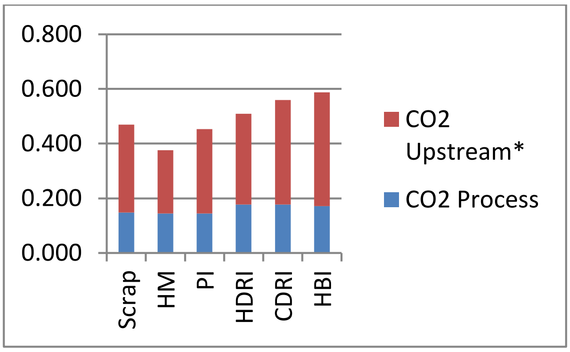

Fig. 4 Global Warming Potential expressed as CO2

Upstream CO_2 is the main emission that is caused when producing the raw materials and energy products. Process CO_2 is the emissions from the process itself. Most of the upstream CO_2 from scrap comes from electricity and the virgin materials from the reduction process. In this example a coal- based electricity is used. However, the figure for scrap would change drastically if for example nuclear power was used instead.

5. Discussion

To draw conclusions from cost calculations is always tricky, since raw material prices are highly volatile. In 2014, both the iron ore and oil prices have decreased drastically whereas the scrap price has showed a more modest alteration. With the ViU calculation using scrap as a reference case you can avoid some of the uncertainties of comparing assumed actual costs.

Using virgin material in order to abate the level of tramp elements will probably be a more common practice in the future. The higher carbon content improves the CO_2 generation within the melt, which result in lower nitrogen levels. [8]

Using HM is primarily a Chinese practice for more reasons than just quality. However, using a conventional EAF with HM results in large off gas volumes and high levels of particles. These might cause environmental problems. PI was traded at 40-100 USD over a premium scrap (A3) in 2014. Compared to the calculated premium of 20 EUR it seems that the market appreciates the known analysis of PI compared to scrap. HDRI is mainly used in integrated DR-plants and the price is dependent on the price of natural gas. They seldom use large amounts of scrap, but that may be changed in the future. Nucor produces CDRI in its plant in Louisiana where the shale gas price is around 50% of the price in the Gulf. The CDRI is then transported to their inland plants along the Mississippi river. Finally, HBI is used in smaller amounts to assess a low tramp element charge in many plants and traded at price levels far higher than the 150 EUR estimated here. One might wonder if the data cannot be interpreted that there is a strong potential for a better scrap processing and sorting. Furthermore, that indicates better ways to measure the levels of tramp elements in old scrap. In a market survey by the International Iron Metallics Association, IIMA, PI is traded at a price 10% over the price of premium scrap whereas HBI is traded 10%-20% under the premium scrap [9].

The final conclusion is therefore that raw material users and traders might find it valuable to look at the ViU for the materials in order to establish a market price reflecting the value the different materials bring to the steelmakers.

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