An Investigation of Air Emission Levels from Distinct Iron and Steel Production Processes with the Adoption of Pollution Control and Pollution Prevention Alternatives

Márcio Macedo Costa[1], Federal University of Rio de Janeiro, Brazil
Roberto Schaeffer, Federal University of Rio de Janeiro, Brazil

ABSTRACT

This paper aims to investigate environmental aspects from different iron and steel production processes. A methodology based on material flows is developed in order to verify some air emission levels attained by Pollution Control and Pollution Prevention alternatives.

The data basis for modelling energy and materials flows in iron and steel production is obtained from a literature review on different technological processes, energy and materials consumption and pollutant releases to the environment. Modelling combines both process analysis and input-output techniques to simulate the different iron and steel production routes and to estimate the resulting total atmospheric pollution releases based on air emission factors for several pollutants by each production step.

Processes examined include: (1) Conventional Integrated (100% ore-based and partly scrap-based); (2) Mini-mill with EAF (100% scrap-based and partly DRI-based); and (3) New Integrated based on the COREX smelting reduction process. Among the alternatives considered for air emissions reductions are those related to Pollution Control (mainly gas cleaning systems) and to Pollution Prevention (change/reduction in input materials, operational procedures and housekeeping improvements, on-site recycling and technology innovations and modifications).

Results indicate higher air pollution intensity for the Conventional Integrated Route over the Mini-mill with EAF and COREX smelting reduction processes, though pointing out that final figures are strongly affected by the systems' boundaries and the different air emission levels of each production step.

Introduction

Over the last twenty-five years concern on industrial energy efficiency has led to the adoption of less consuming technologies based on new equipments and operational procedures. Despite significant achievements, the "energy efficiency wave" still has a long way to go in order to attain sustainable development. It seems that the same course has been followed, although with some delay, by a "pollution reduction wave." Environmental management has changed since the early 70's, when the main approach in dealing with pollution was to relocate or dilute it, in order to minimize its local impacts. After that, growing spread of ecological values has led to large investments in end-of-pipe pollution controls. A recent approach relies on cleaner production, which means avoiding or minimizing the generation of emissions, effluents and solid wastes at the source of pollution.

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[1] Currently on leave at Lawrence Berkeley National Laboratory (LBNL), Berkeley, CA

The evolution of the Iron and Steel Industry constitutes an interesting case for technology analysis from several points-of-view, from the search for new technologies to the selection of available technologies at any particular time. First, iron and steel production processes are highly energy-intensive and involve diverse and huge amounts of pollutant releases. Second, the Iron and Steel Industry is facing a competitive challenge imposed by other material production costs and performances (Fruehan 1996). Third, more stringent environmental regulatory requirements over pollutant releases have decisively affected technology choices. Nowadays, it is possible to clearly identify some trends in industry towards integrating economic, strategic and environmental issues.

Despite major investments in pollution control, which has led to a successful reduction of pollutant discharges, further technological improvements are necessary to reduce costs, increase profitability and facilitate compliance with environmental regulations. General concern coming from industry associations, environmental protection agencies and society in general reveals a changing perspective through an integration of pollution control and pollution prevention activities (AISI 1997; EPA 1996; OECD 1991).

It is far from an easy task to try to set meaning and reliable ranges for pollutants discharges. A precautionary work must be done in order to allow comparisons to be made, and conclusions to be drawn, about firms' performances from pollution emission data. Several sources of difference and uncertainty still remain regarding data on iron and steel production systems. Reported emissions data cannot be explained based on differences in abatement devices and environmental operational efficiency measures only. Other factors, like different measurement methods, age and design of plants, material inputs and local conditions, may have a strong influence over the final results too.

Although data collection on emission parameters is still largely incomplete and not standardized, valuable efforts of gathering data from a large number of firms can contribute to future programs. This paper leans mainly on two interconnected databases: (1) an European Community extensive research based on questionnaires answered by firms regarding emission data for several production steps, which seems to be highly representative of the "European iron and steel production system" as it comes from 166 firms from 12 countries, accounting for some 77% of total production (EC 1996); and (2) a draft document on Best Available Techniques (BAT) that presents recommended emission factors based on firms adopting BAT around the world (EIPPCB 1998). Our work draws a line between the so-called End-of-pipe and Process-integrated techniques, named here Pollution Control (PC) and Pollution Prevention (PP) technologies, respectively.

The objective of this paper is to set representative ranges for air emission factors levels by production step and to verify the corresponding air emissions for different production routes. A model of material flows of iron and steel production systems has been developed in order to simulate the environmental effects of different material inputs, PC and PP technologies and process changes. *Actually, what we present here are but preliminary results of a broader research effort underway on the Industrial Ecology of Iron and Steel Production Systems.* That larger effort refers not only to air emissions but also to water effluents and solid wastes. A more reliable environmental assessment requires necessarily taking into account, simultaneously, all media: Air, Water and Land.

Scope and main assumptions

Liquid Carbon Steel is chosen as the reference product. Casting, Rolling and Finishing Production Steps are expected to be included later in our longer-term, broader research effort, which will allow the assessment of product diversity effects on pollution release from the Iron and Steel Industry.

Three main processes are considered here: Conventional Integrated Works (Pelletization, Sinter and Coke Plants – Blast Furnace – Basic Oxygen Furnace route), Semi-integrated Works (Pelletization and DRI Plants - Electric Arc Furnace route) and New Integrated Works with Smelting Reduction (Pelletization Plant - COREX - BOF route). Input data include current material/energy specific consumption and air emission factors (e.g., kg of material or pollutant per unit of product from a given production step) for different processes. Output from the model developed comprises total mass of each pollutant released to the atmosphere, adding contributions over all production steps. In spite of the fact that the use of emission factors is suitable for comparing alternative techniques, environmental impacts might relate to the concentration of pollutants in gas streams in the receiving media and/or chronic loads over time of a given pollutant (EIPPCB 1998).

Atmospheric emissions of particulate matter, carbon/sulfur/nitrogen oxides, and acid/organic/heavy metals emissions are included among the most significant environmental issues for steelmaking. In this analysis, Carbon Dioxide (CO_2), chlorofluorocarbons (CFCs), radioactive elements and heavy metals are disconsidered. Emission factors for the following pollutants are given: Dust, Nitrogen Oxides (NO_x), Sulfur Dioxide (SO_2), Carbon Monoxide (CO), Hydrochloric Acid (HCl), Hydrogen Fluoride (HF), Hydrogen Sulfide (H_2S), Polycyclic Aromatic Hydrocarbons (PAH), Volatile Organic Compounds (VOC), Polychlorinated Biphenyl (PCB), Polychlorinated Dibenzo-p-dioxins and Furans (PCDD/F), Benzene and Chlorobenzene.

Besides the more general types of processes, techniques are categorized in two main groups: (1) Pollution Control (PC) and (2) Pollution Prevention (PP). Techniques cited as PC have also been named as end-of-pipe techniques and consist mainly of gas cleaning systems. There are four main types of gas cleaning systems (IISI & UNEP 1997):

- *Dry Cyclones*, where particles are separated from the waste gas by centrifugal action. Cyclones can only remove coarser particles and, as such, operate at a lower efficiency;
- *Electrostatic Precipitators (ESP)*, which apply an electrical charge to the particles of dust, causing them to be attracted and captured by the dust collecting electrode. ESPs generally operate with more than 90% efficiency, have lower energy consumption, but are unsuitable to highly resistive dusts;
- *Wet Scrubbers*, which separate a wider range of pollutants by washing the waste gas with a stream of water droplets. Wet Scrubbers require water treatment devices to clean and recycle the water back to the scrubber; and
- *Fabric Filters*, where particles are separated from the waste gas at the surface of a cloth filter, providing higher cleaning efficiencies. The down side is that filters can operate over a limited range of temperature and moisture conditions only.

Gas cleaning systems commonly operate with a combination of these devices, including not only cleaning but also collecting apparatuses. Other arrangements are present in the case of lime desulphurization and denitrification using catalysts or activated carbon process (EIPPCB 1998).

There is a wide range of Pollution Prevention technologies available for all production steps. Technologies can be classified as:

- *Technology modifications*, which include new or improved equipment, automation and layout changes;
- *Change or reduction of inputs*, which include materials and/or energy carriers;
- *Energy efficient measures*;
- *Operational procedures and housekeeping improvements; and*
- *On-site recycling*

Model Description

Modelling iron and steel production systems faces the inherent complexity of the various processes. As our main goal is to simulate the resulting effects of different combinations of processes and technologies on pollution discharge levels, general assumptions and simplifications are required. Actually, the model has been developed in a simplified way to allow simple simulations and, furthermore, meaningful conclusions from production systems above the firm's level. However, for a comprehensive modelling at the firm's level some additional work on particular conditions are still required, mainly in dealing with economic analyses. Even so, the model is expected, in the future, to be able to represent any iron and steel production system as long as appropriate data are provided.

Each production step has a primary output: a main product that is sent to the next step. So, it is possible to define a commodity matrix Z that represents these product exchanges, where z_{ij} is the flow of input from step i (coke for example) to step j (Blast Furnace, for example). From $\mathbf{Z}$ and $\mathbf{X}_j$, the total output of j, an $\mathbf{A}$ matrix of technical coefficients $\mathbf{a}_{ij}$ is obtained, where:

$$\mathbf{a}_{ij} = z_{ij}/\mathbf{X}_j \qquad (1)$$

For instance, $\mathbf{a}_{ij}$ can represent the mass of coke necessary to produce one metric tonne (t) of pig iron in the Blast Furnace. Vector $\mathbf{X}$ represents the direct and indirect effects of production. From Leontief reasoning (Lave et al. 1995; Miller & Blair 1985) and considering $\mathbf{Y}$ the final demand vector (the considered last step, for example Casting, that uses crude steel), we have:

$$\mathbf{X} - \mathbf{AX} = \mathbf{Y} \quad \Rightarrow \quad \mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{Y} \qquad (2)$$

To include pollutants emissions, a $\mathbf{D}$ matrix is defined indicating the emission of each pollutant i per metric tonne of products from each one of the various steps of production j. Each $\mathbf{d}_{ij}$ represents the output of a specific model applied to material flows in each production step. Vector $\mathbf{X}^*$ represents the total effect of pollution:

$$\mathbf{X}^* = \mathbf{D}\,\mathbf{X} \quad \Rightarrow \quad \mathbf{X}^* = [\mathbf{D}\,(\mathbf{I} - \mathbf{A})^{-1}]\mathbf{Y} \qquad (3)$$

It is important to mention that this is just one way of modelling energy and material flows in the Iron and Steel Industry. Other kinds of models are required for a more comprehensive approach of these flows, including those flows that incorporate the simultaneous production of by-products. Table 1 presents possible Technical Coefficients Matrices (A's) for Integrated, Semi-integrated and New Integrated Works derived from data collected from the literature (AISI 1997; EC 1996; Eberle, Schiffer & Siuka 1997; EICCPB 1998; IISI & UNEP 1997; MIDREX 1998). As indicated in equation (1), each a_{ij} represents the mass, in metric tonnes (t) for example, of a given product (rows) necessary to produce one metric tonne (t) of each product from the production steps (columns). Other possible flows are simulated to measure the decisive role of quantitative and qualitative changes of material inputs over pollutants total discharges.

Table 1. Technical Coefficients Matrix (A) by Selected Processes

Integrated Works

	Fluxes	Iron Ore	Pellet Plant	Sinter Plant	Coal	Coke Plant	Scrap	BF	BOF
Fluxes	0	0	0.031	0.15	0	0	0	0.001	0.045
Iron Ore	0	0	1.025	0.95	0	0	0	0.15	0.015
Pellets	0	0	0	0	0	0	0	0.435	0
Sinter	0	0	0	0	0	0	0	1.16	0
Coal	0	0	0	0	0	1.25	0	0.084	0
Coke	0	0	0.009	0.046	0	0	0	0.358	0
Scrap	0	0	0	0	0	0	0	0	0.128
Pig Iron	0	0	0	0	0	0	0	0	0.94
BOF liq.steel	0	0	0	0	0	0	0	0	0

Semi-integrated Works

	Fluxes	Coal	Iron Ore	Pellet Plant	DRI	Alloys	Scrap	EAF
Fluxes	0	0	0	0	0	0	0	0.067
Coal	0	0	0	0	0	0	0	0.015
Iron Ore	0	0	0	1.025	0	0	0	0.000
Pellets	0	0	0	0	1.418	0	0	0.000
DRI	0	0	0	0	0	0	0	0.196
Alloys	0	0	0	0	0	0	0	0.010
Scrap	0	0	0	0	0	0	0	0.874
EAF liq.steel	0	0	0	0	0	0	0	0.000

New Integrated Works

	Iron Ore	Fluxes	Pellet Plant	Coal	COREX	BOF
Iron Ore	0	0	1.025	0	0.444	0
Pellets	0	0	0	0	1.036	0
Fluxes	0	0	0.031	0	0.325	0
Coal	0	0	0	0	0.990	0
COREX h.m.	0	0	0	0	0	1.096
BOF liq.steel	0	0	0	0	0	0

The emission factors derived from the D matrices are presented in Tables 2 to 8 for each production step, by air emission levels (DOE 1996; EC 1996; EICCPB 1998), i.e., emissions that are released to the environment and that can be classified as:

- *Low*, when are based on PP and PC Best Available Techniques;

- *Average*, when are based on average emission factors for the Iron an Steel Industry in Europe, and as such are derived from a set of plants;
- *High*, when are based on less efficient techniques or procedures; and
- *Uncontrolled*, which represent extreme values due to the lack of control devices of any sort, malfunctioning of gas cleaning systems or input particular conditions.

Lack of appropriate data makes impossible, at this stage, the inclusion of emissions from the Iron Ore and Coal (mining and also handling inside the steel plant), Fluxes (mining, production and handling), Scrap (preparation), Alloys (production) sectors. DRI sector considers only Pelletization Plants emissions due to the lack of DRI Plant emission data. *We do not provide a detailed description of alternatives according to the air emission levels. In spite of using representative data for the given air emission levels, particular conditions lead to a wide range of data even in case of adoption of similar alternatives among firms.*

Table 2 – Air Emission Factors for Pelletization Plants by Selected Levels

Pelletization Plants		Level of air emissions			
Emission factors		LOW	AVERAGE	HIGH	UNCONTROLLED
Dust	g/t pellets	100	168	672	3360
SO_2	g/t pellets	23	250	500	720
NOx	g/t pellets	140	510	740	970
CO	g/t pellets	410	410	615	615
VOC	g/t pellets	40	40	40	40
HCl	g/t pellets	2	48	48	319
HF	g/t pellets	0.8	39	39	187
PAH	mg/t pellets	0.19	0.19	0.19	0.19
PCDD/F	mg I-TEQ/t pellets	0.006	0.006	0.006	0.006

Notes: (1) Including emissions from Grinding, Induration, Drying and Screening; (2) PC alternatives: scrubbers, semi-dry desulphurisation + de-dusting (gas suspension absorber), denitrification (Selective Catalytic Reduction); (3) PP alternatives: process-integrated NOx abatement (low nitrogen content of fuel and limitation of O_2 excess), recovery of sensible heat from induration strand; (4) VOC, PAH, PCDD/F – single data (EIPPCB 1998); (5) Own elaboration based on DOE (1996), EC (1996) and EIPPCB (1998).

Table 3 - Air Emission Factors for Sinter Plants by Selected Levels

Sinter Plants		Level of air emissions			
Emission factors		LOW	AVERAGE	HIGH	UNCONTROLLED
Dust	g/t sinter	180	425	880	7400
SO_2	g/t sinter	120	970	1450	2000
NOx	g/t sinter	85	580	760	920
CO	g/t sinter	15900	19600	25300	25300
VOC	g/t sinter	25	150	200	150
HCl	g/t sinter	21	54	87	312
HF	g/t sinter	1.3	9.5	20	57
PAH	mg/t sinter	105	105	839	839
PCB	mg/t sinter	6	12	12	12
PCDD/F	mg I-TEQ/t sinter	0.8	10	21	90

Notes: (1) Including emissions from Crushing, Sinter Strand (windbox), Discharge Zone, Sinter Cooling; (2) PC alternatives: high-level with cyclones, average-level with ESP, low-level with ESP + scrubber or ESP + fabric filters, wet desulphurisation, denitrification (Selective Catalytic Reduction); (3) PP alternatives: lowering sulphur content of the sinter feed, heat recovery from Sinter Strand and Sinter Cooling, Emission Optimised Sintering (EOS); (4) Own elaboration based on DOE (1996), EC (1996) and EIPPCB (1998).

Table 4 - Air Emission Factors for Coke Oven Plants by Selected Levels

Coke Oven Plants		Level of air emissions			
Emission factors		LOW	AVERAGE	HIGH	UNCONTROLLED
Dust	g/t coke	50	300	730	3000
SO_2	g/t coke	80	400	2800	4200
NOx	g/t coke	50	300	1782	2400
CO	g/t coke	400	1000	1500	1500
VOC	g/t coke	12	24	24	1915
H_2S	g/t coke	21	80	80	2500
PAH	mg/t coke	143	300	1000	7000
Benzene	g/t coke	1.2	20	46	46

Notes: (1) Including emissions from Coal Charging, Coking, Coke Pushing, Quenching, Coke Gas Combustion and Coke Gas Purifying. Discontinuous emissions from Coke Oven Plants are difficult to quantify and there are a wide range of emission factors, strongly dependent on plant specific parameters; (2) PC alternatives: charging cars, water sealed ascension pipes, de-dusting of Coke Pushing emissions with integrated hood plus fabric filters, Coke Gas desulphurisation; (3) PP alternatives: extensive maintenance and cleaning, smooth operation, improvement of oven doors and frame seals, Coke Dry Quenching (CDQ), reducing of NOx formation with low flame temperature techniques, e.g. stage combustion; (4) Own elaboration based on DOE (1996), EC (1996) and EIPPCB (1998).

Table 5 – Air Emission Factors for Blast Furnaces by Selected Levels

Blast Furnaces		Level of air emissions			
Emission factors		LOW	AVERAGE	HIGH	UNCONTROLLED
Dust	g/t pig iron	20	77	194	40000
SO_2	g/t pig iron	60	269	473	800
NOx	g/t pig iron	11	160	211	597
CO	g/t pig iron	82	977	1548	2700
H_2S	g/t pig iron	1.3	107	218	364
PCDD/F	mg I-TEQ/t p.iron	0.001	0.004	n.a.	n.a.

Notes: (1) Including emissions from Charging Zone, Coal Injection Preparation, Cast House, Hot Stoves and Slag Granulation; (2) PC alternatives: de-dusting of BF Gas (cyclones + scrubbers), vapour condensation to reduce emissions from Slag Granulation, de-dusting of secondary emissions (fabric filters, scrubbers or ESP); (3) PP alternatives: coal injection, BF gas recovery, top gas power recovery turbines; (4) n.a. – not available; (5) Own elaboration based on DOE (1996), EC (1996) and EIPPCB (1998).

Table 6 – Air Emission Factors for Basic Oxygen Furnaces by Selected Levels

Basic Oxygen Furnaces		Level of air emissions			
Emission factors		LOW	AVERAGE	HIGH	UNCONTROLLED
Dust	g/t liquid steel	13	96	280	15000
SO_2	g/t liquid steel	2	18	20	20
NOx	g/t liquid steel	5	28	150	150
CO	g/t liquid steel	1000	4000	8000	16000
PAH	g/t liquid steel	0.08	0.16	0.8	1.6
PCDD/F	mg I-TEQ/t liq.st.	0.001	0.006	0.01	0.06

Notes: (1) Including emissions from Hot Metal Desulphurisation, Converter, Blowing (secondary), Charging, Tapping, Deslagging and Ladle Metallurgy; (2) PC alternatives: scrubbers for primary de-dusting, fabric filters or ESP for pig iron pre-treatment and de-dusting of secondary off-gases; (3) PP alternatives: suppressed combustion with BOF gas recovery (low level), full combustion (high level), heat recovery of sensible heat BOF gas; (4) Own elaboration based on DOE (1996), EC (1996) and EIPPCB (1998).

Table 7 – Air Emission Factors for Electric Arc Furnaces by Selected Levels

Electric Arc Furnaces		Level of air emissions			
Emission factors		LOW	AVERAGE	HIGH	UNCONTROLLED
Dust	g/t liquid steel	10	124	300	15000
SO_2	g/t liquid steel	30	120	300	400
NOx	g/t liquid steel	85	250	334	454
CO	g/t liquid steel	2500	2500	3000	3000
VOC	g/t liquid steel	1	21	69	160
H_2S	g/t liquid steel	0	0	0	0
HCl	g/t liquid steel	0.6	3.2	7	n.a.
HF	g/t liquid steel	0.4	2.9	5.3	n.a.
PAH	mg/t liquid steel	26	225	920	n.a.
PCB	mg/t liquid steel	5.6	13	34	n.a.
PCDD/F	mg I-TEQ/t liq.st.	0.3	4	12	n.a.
Benzene	g/t liquid steel	0.2	1.4	3.1	38
Chlorobenz.	mg/t liquid steel	3	22	37	135

Notes: (1) Including emissions from Scrap Pre-heating, Charging, Melting, Refining, Steel and Slag Tapping, Ladle Metallurgy; (2) PC alternatives: dust collecting systems (4th hole and evacuation of building atmosphere or dog-house), fabric filters, injection of lignite powder to reduce PCDD/F and PCB emissions; (3) PP alternatives: energy efficient techniques (UHP furnaces, oxy-fuel burners, oxygen post-combustion, scrap pre-heating; (4) n.a. – not available; (5) Own elaboration based on DOE (1996), EC (1996) and EIPPCB (1998).

Table 8 – Air Emission Factors for COREX Plants by Selected Levels

COREX Plants		Level of air emissions			
Emission factors		LOW	AVERAGE	HIGH	UNCONTROLLED
Dust	g/t hot metal	39	130	139	n.a.
SO_2	g/t hot metal	26	53	333	n.a.
NOx	g/t hot metal	21	33	114	n.a.

Notes: (1) Including Reduction Shaft and Melter-Gasifier; (2) Few data available for air emissions; (3) PC alternatives: de-dusting of Melter-Gasifier emissions with hot gas cyclone + scrubber, reduction gas and top gas cleaning with scrubbers (4) n.a. – not available; (5) Own elaboration based on Eberle, Schiffer and Siuka (1997).

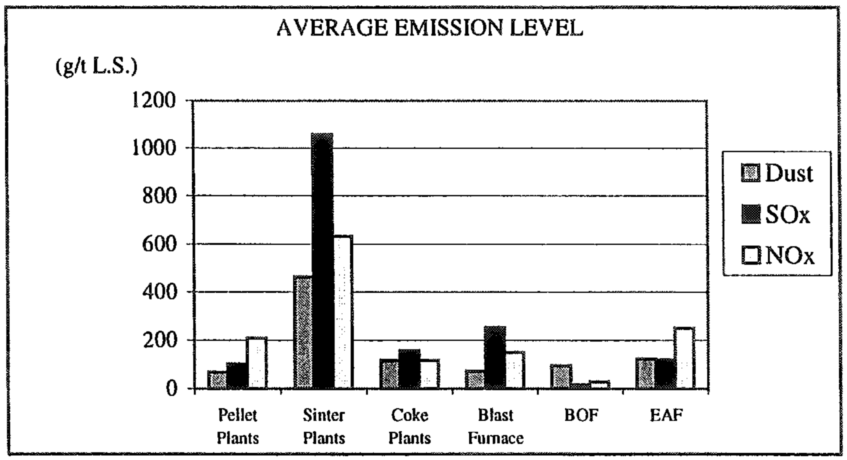
Results and Discussion

The model is applied to the reference of one metric tonne (t) of liquid carbon steel derived from the four air emission levels of each one of the three production processes considered (Table 9). These final results show the total air pollutants releases under the cited scope and assumptions. Figure 1 presents dust, NOx and SOx emission factors for low and average levels by production step. The results are based on material input assumptions used to fill A matrices, as shown in Table 1.

First, it is necessary to reaffirm the previous warnings about the wide range of emission factors, which can be influenced by several reasons based on diversity of equipment, operational procedures, material input and measuring methods. Our effort was driven to set some meaningful air emissions levels (Low, Average, High and Uncontrolled) in order to better assess some environmental issues regarding iron and steel production systems. Therefore, values were given, under some assumptions, even admitting the existence of ranges around them.

Table 9 – Total Air Pollutants Releases of Different Production Routes According to Particular Emission Levels

		LOW			AVERAGE			HIGH			UNCONTROLLED		
Emission factors		BF/BOF	EAF	SR/BOF	BF/BOF	EAF	SR/BOF	BF/BOF	EAF	SR/BOF	BF/BOF	EAF	SR/BOF
Dust	g/t liquid steel	288	38	169	818	171	429	2036	637	1195	63375	15934	18967
SO_2	g/t liquid steel	230	36	57	1587	189	360	3551	439	953	5112	600	1202
NOx	g/t liquid steel	185	124	187	1136	392	643	2308	540	1115	3176	724	1376
CO	g/t liquid steel	18738	2614	1466	26848	2614	4466	37991	3171	8698	47043	3171	16698
VOC	g/t liquid steel	48	12	45	189	32	45	246	80	45	1030	171	45
H_2S	g/t liquid steel	9	0	0	132	0	0	242	0	0	1452	0	0
HCl	g/t liquid steel	24	1.2	2.3	79	17	55	114	20	55	471	n.a.	362
HF	g/t liquid steel	2	0.6	0.9	26	14	44	38	16	44	139	n.a.	212
PAH	mg/t liquid steel	170	26	0.3	232	225	0.4	1380	920	1	4024	n.a.	2
PCB	mg/t liquid steel	7	6	0	13	13	0	13	34	0	13	n.a.	0
PCDD/F	mg I-TEQ/t liq.st.	0.9	0.3	0.01	11	4	0.01	24	12	0.02	102	n.a.	n.a.
Benzene	g/t liquid steel	0.5	0.2	0	8	1.4	0	21	3	0	20	14	0
Chlorobenz.	mg/t liquid steel	0	3	0	0	22	0	0	37	0	0	200	0



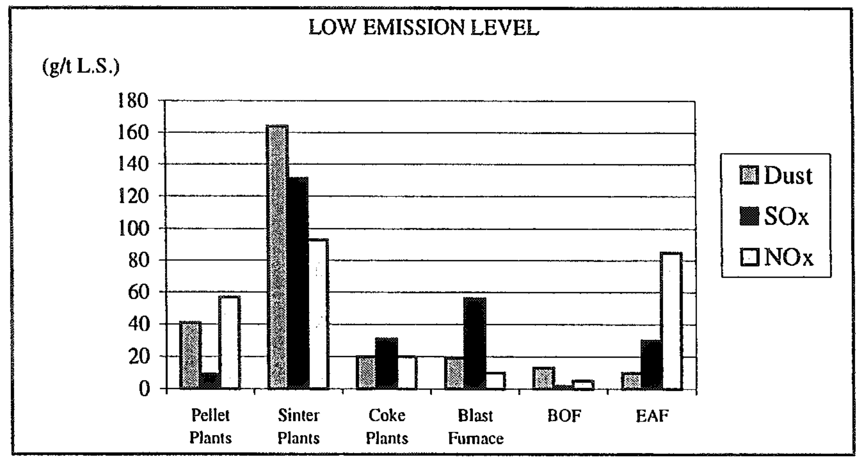


Figure 1 – Average and Low Level Emission Factors of Dust, SOx and NOx by production step (g/t of liquid steel)

Inspite of relatively simple reasoning, the model has been developed to integrate some non-linear (Spengler et al. 1997) and discontinuous relations between material input and emissions. Additional work should be done to incorporate other direct and indirect production steps (Mining, Lime Plant, Electricity and Oxygen Plants), other relevant air emissions accounting, like heavy metals and other environmental media to where effluents and solid wastes are released. Economic analysis remains difficult to be made in a global approach (EC 1996) and depends strongly on particular conditions.

As expected, air pollutants releases from Conventional Integrated are higher than other routes for all given emission levels, nevertheless several plants operating at low emission level can present less air environmental impact compared with other processes plants operating at high emission level (Table 9).

The Semi-integrated (EAF) route presents the lowest emissions levels for dust, NOx, SO_2, CO and VOC. Except for CO emissions, less efficient plants (high level) present pollutants discharge between the low and the average level of the Conventional Integrated route. However, releases of hydrocarbons like PAH and organochlorine compounds, such as chlorobenzenes, PCB and PCDD/F, are relevant and, as such, deserves further attention. Scrap contaminants, mainly zinc from galvanized steel, poses a major problem for EAF production so as to improve recycling and have high quality scrap inputs.

Despite some problems with data availability, it is clear that New Integrated Route with COREX Smelting Reduction process presents many environmental advantages when compared with the Conventional Integrated Route. However, it should be noted that for the high-emission level, emissions from other production steps can lead to higher emission figures for the complete production chain. Organic compounds emissions seem to be irrelevant due to the absence of coke production, but the potential of Smelting Reduction to produce hazardous air pollutants still has to be better evaluated.

For the same emission level, Sinter Plants present higher pollutant discharges for dust, NOx, SO_2, CO (Figure 1). Regarding these pollutants, as well as organic compounds, the adoption of BAT in Sinter Plants constitute an important issue for improving environmental performance of Conventional Integrated Works as a whole. Many plants have difficulties with keeping operations in compliance with environmental regulations. In spite of this, Sinter Plants remain an important metal recycling production step for by-products, like dust from gas cleaning systems, sludges and scales.

Pelletization Plants are generally excluded from emissions accounting in Iron and Steel Production Systems, probably because the more common are the stand-alone plants. But our results indicate that emissions from Pelletization Plants are far from negligible even within the low-level category. As the use of pellets has increased in conventional integrated plants, DRI production and Smelting Reduction Plants, environmental and technological issues should be addressed.

Coke Ovens Plants require a wide range of PP and PC techniques to reduce emissions mainly of dust, NOx, SO_2, H_2S and organic compounds. Several PP techniques, like smooth operation, maintenance and oven door improvements are relevant to achieve these reductions but BAT include high cost PC techniques, like flue gas catalytic denitrification, desulphurisation processes and Coke Dry Quenching. Relatively low emissions for plants operating at low and average emission levels (Figure 1) indicate a high pollution reduction potential for the former and the present european concern over Coke Plants emissions for the latter. However, high-level emission figures bring forward major dificulties for dust, SOx and organic compounds emissions reduction, in particular for old plants.

Energy efficient measures have been one of the most effective sets of Pollution Prevention alternatives for emissions reduction. Coal injection to the Blast Furnace and lower coke breeze consumption in Sinter Plants play an important role in reducing coke requirements. Simulations using much higher coke production, even at low emission level for Coke Plants, have led to a substantial increase in Conventional Integrated route emissions. Several alternatives, like UHP furnaces, oxy-fuel burners, oxygen post-combustion, improved process control and scrap pre-heating, are available for decreasing electricity consumption in EAF Plants. Depending on overall emissions, including those from electricity production and scrap preparation, EAF route advantages over other routes can be reduced. A more complete emissions balance should include emissions from increasing oxygen production for EAF and Smelting Reduction routes.

It seems that EAF and Smelting Reduction routes cannot be the total answer to product and environmental issues (Szekely 1995) even in the medium-term. Although the production from these routes will likely continue to increase, Conventional Integrated plants still comprise more than 50% of world steel production. Therefore, a prompt response to environmental issues comprises an Integrated Pollution Prevention and Control approach as guidance for eco-management systems.

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