“Capacity Building and Strengthening Institutional Arrangement”

Workshop: “Best Available Techniques (BAT)

BREF on Smelter and Metal Industries

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APAT

Agency for Environmental Protection and Technical Services

Index

1. Introduction

The most important environmental issues of iron and steelmaking relate to emissions to air and to solid wastes/by-products. Wastewater emissions from coke oven plants, blast furnaces and basic oxygen furnaces are the most relevant emissions to water in this sector.

Only limited information is available about noise/vibration emissions and related measures to minimise them.

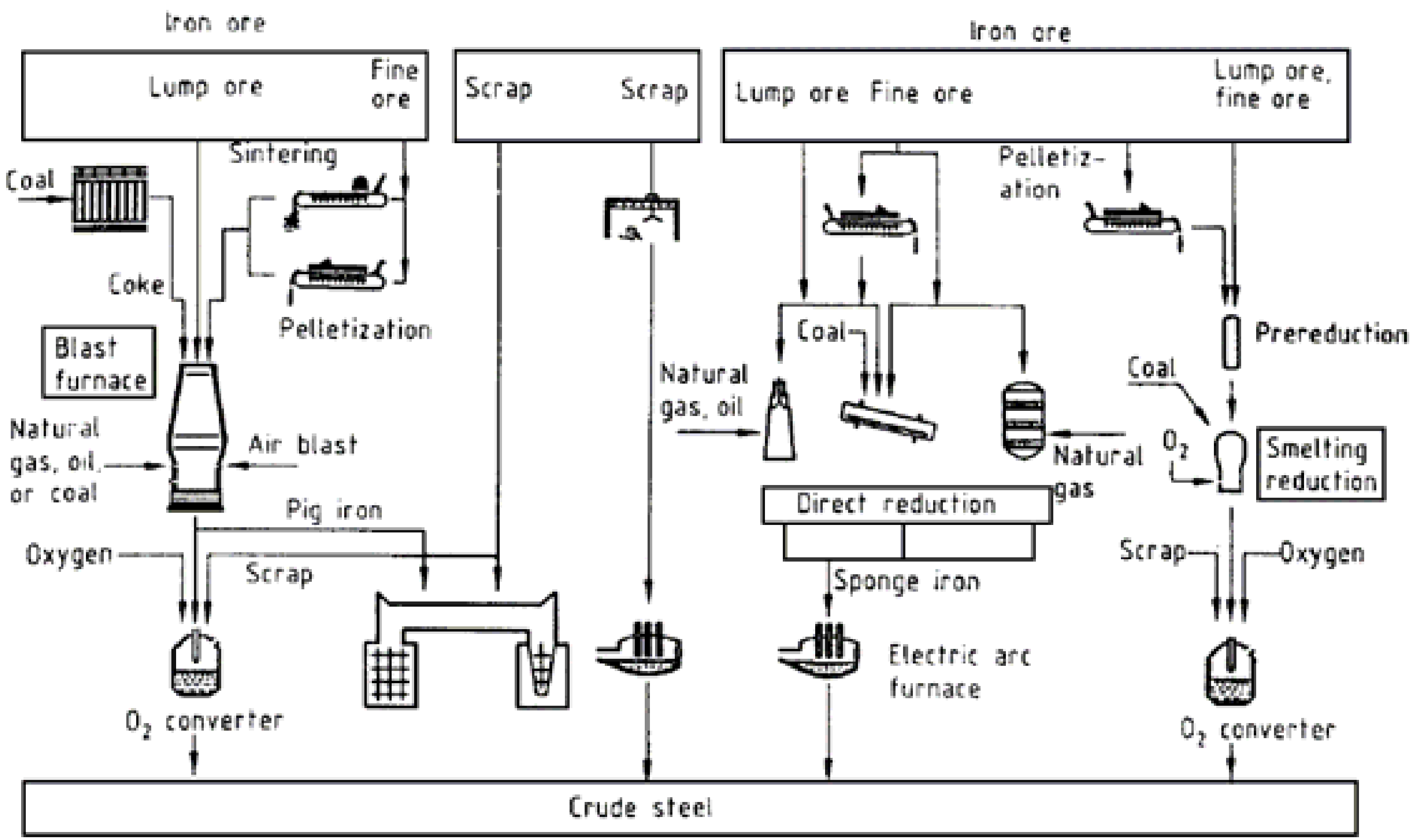
2. Productive Cycles

Steel-making process routes

- ***Four routes*** are currently used for the production of steel: the classic blast furnace/basic-oxygen furnace route, direct melting of scrap (electric arc furnace), smelting reduction and direct reduction.

- In the next figure are shown crude steel production methods [Ullmann’s, 1994].

2. Productive Cycles



2. Productive Cycles

Steel-making process routes

- At present (1998), EU (15) steel production is based on the blast furnace/ basic-oxygen route (approximately 65%) and the Electric Arc Furnace (EAF) route (approximately 35%).
- The percentage of world crude steel production via smelting and direct reduction was about 4% in 1996 [Hille, 1997].
- In Europe production of Direct Reduced Iron (DRI) is limited to about 500000 t/a (Germany and Sweden) representing approximately 1.5% of world output.

2. Productive Cycles

Steel-making process routes

- Consumption of DRI in EAF steel-making was reported to be 400000 t in the EU (15) in 1995, but interest in this material is increasing and new production technologies are emerging.

- In the EU (15), there are currently no smelting reduction units on a commercial scale.

2. Productive Cycles

Integrated steelworks

- Of the four steel-making routes described the classic blast furnace/basic oxygen furnace route is by far the most complex, taking place in large industrial complexes known as integrated steelworks, covering areas up to several square kilometres.
- Integrated steelworks are characterised by networks of interdependent material and energy flows between the various production units, most of which are sinter plants, pelletisation plants, coke oven plants, blast furnaces and basic oxygen steel-making plants with subsequent casting.

2. Productive Cycles

Aerial view of an Integrated Steelworks located near the coast

2. Productive Cycles

Integrated steelworks

- In an integrated steel works the blast furnace is the main operational unit where the primary reduction of oxide ores takes place leading to liquid iron, so-called pig iron.
- Modern high performance blast furnaces require physical and metallurgical preparation of the burden.
- The two types of iron ore preparation plants are the sinter plants and the pellet plants.
- Pellets are nearly always made from one well-defined iron ore or concentrate at the mine and are transported in this form.

2. Productive Cycles

Integrated steelworks

- In Europe there is only one integrated steelworks also operating a pelletisation plant.
- Sinter is generally produced at the ironworks from predesigned mixtures of fine ores, residues and additives.
- The main reducing agents in a blast furnace are coke and powdered coal forming carbon monoxide and hydrogen which reduce the iron oxides. Coke and coal also partly act as a fuel.

2. Productive Cycles

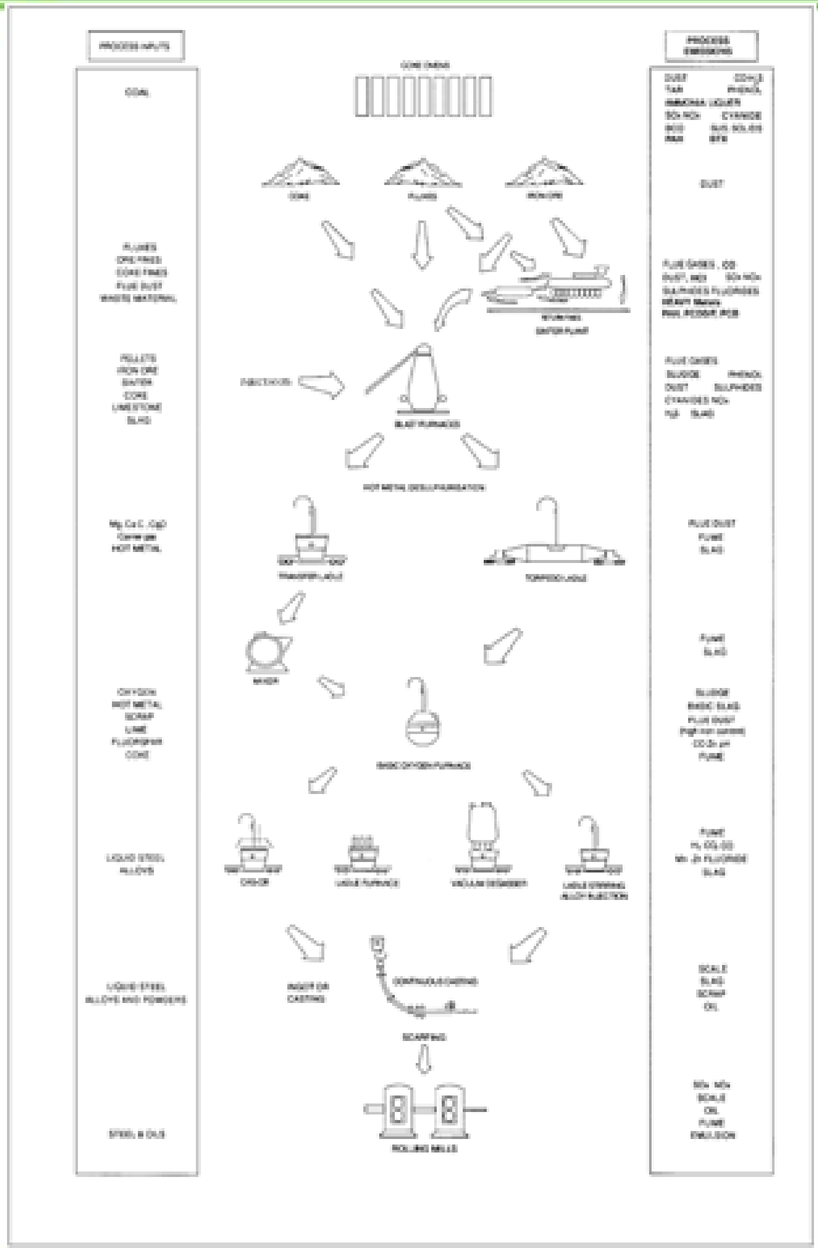
Integrated steelworks

- Coke is produced from coal by means of dry distillation in a coke oven and has better physical and chemical characteristics than coal.
- In many cases, additional reducing agents/fuels are supplied by injection of oil, natural gas and (in a few cases) plastics.
- A hot blast provides the necessary oxygen to form the carbon monoxide (CO), which is the basic reducing agent for the iron oxides.

2. Productive Cycles

Integrated steelworks

- The blast furnace is charged at the top with burden consists of alternate layers of coke and a mixtures of sinter and/or pellets, lump ore and fluxes.
- In the furnace the iron ore is increasingly reduced and liquid iron and slag are collected in the bottom of the furnace, from where they are tapped.
- The slag from the blast furnace is granulated, pelletised, or tapped into slag pits. The slag granules or pellets are usually sold to cement manufacturing companies. Also, slag from pits can be used in road construction.



Overview of the process route of an integrated steel works - [UK IPR 2/1, 1994]

2. Productive Cycles

Integrated steelworks

- The liquid iron from the blast furnace (pig iron) is transported to a basic oxygen furnace, where the carbon content (approx. 4%) is lowered to less than 1%, thereby resulting in steel.
- On leaving the basic oxygen furnace the liquid steel is cast, either into ingots or by means of continuous casting.
- Casting products, whether ingots, slabs, billets or blooms, are subsequently processed in rolling mills and product finishing lines in order to prepare them for market.

2. Productive Cycles

Sinter Plants

- Modern high-performance blast furnaces achieve improved performance by prior physical and metallurgical preparation of the burden which improves permeability and reducibility.

- This preparation entails agglomerating the furnace charge either by sintering or pelletisation.

- The charge consists of a mixture of fine ores, additives, iron-bearing recycled materials from downstream operations such as coarse dust and sludge from blast-furnace gas (BFgas) cleaning, mill scale, casting scale, etc. to which coke breeze is added enabling the ignition of it.

2. Productive Cycles

Sinter Plants

- In Europe, down draft sintering on continuous travelling grates is exclusively used.

- Photograph of a sinter strand with the charging facility (drums or chutes) and the ignition canopy at the starting end

2. Productive Cycles

Pelletisation plants

- Pelletisation and sintering of iron ore are complementary process routes for the preparation of iron oxide raw materials for primary iron and steel making.

- For various reasons, sinter is practically always produced at the steel works side: it allows solid wastes to be recycled; coke breeze is available at steel works for use as a fuel; sinter is prone to degradation during transport and handling.

2. Productive Cycles

Pelletisation plants

- Pellets are formed from the raw materials . fine ore and additives of < 0.05 mm - into 9-16 mm spheres using very high temperatures and this is mainly carried on at the site of the mine or its shipping port.
- In the EU 15 there is only one integrated steel works which includes a pelletisation plant (in the Netherlands). Sweden has four stand-alone pelletisation plants.
- Pellet production in the five EU plants mentioned above was 15.1 Mt in 1996.
- In 1995 total pellet consumption in the EU 15 was about 35 Mt whereas sinter consumption was three times higher.

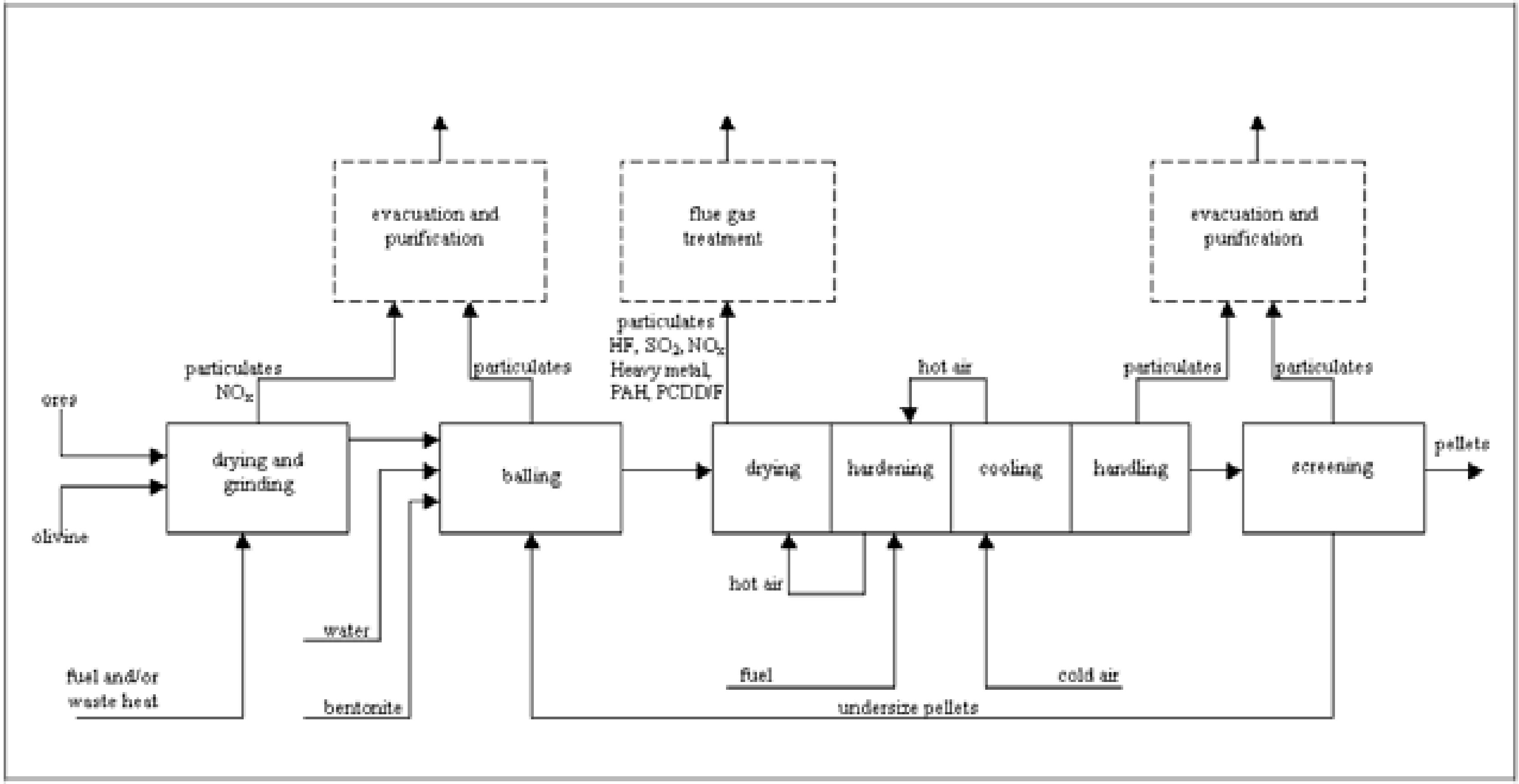
2. Productive Cycles

Balling drum as part of a pelletisation plant

2. Productive Cycles

The pelletisation process consists of grinding and drying or de-watering, balling and induration followed by screening and handling.

Schematic of a pelletisation plant – [InfoMil, 1997]



2. Productive Cycles

Coke oven plants

- Coal pyrolysis means the heating of coal in an oxidation free atmosphere to produce gases, liquids and a solid residue (char or ***coke***). Coal pyrolysis at high temperature is called carbonisation.
- In this process the temperature of the flue gases is normally 1150 – 1350 °C indirectly heating the coal up to 1000 – 1100 °C for 14 – 24 hours.
- This produces blast furnace and foundry ***cokes***.
- ***Coke*** is the primary reducing agent in blast furnaces and can not be wholly replaced by other fuels such as coal.

2. Productive Cycles

Coke oven plants

- Coke functions both as a support material and as a matrix through which gas circulates in the stock column.

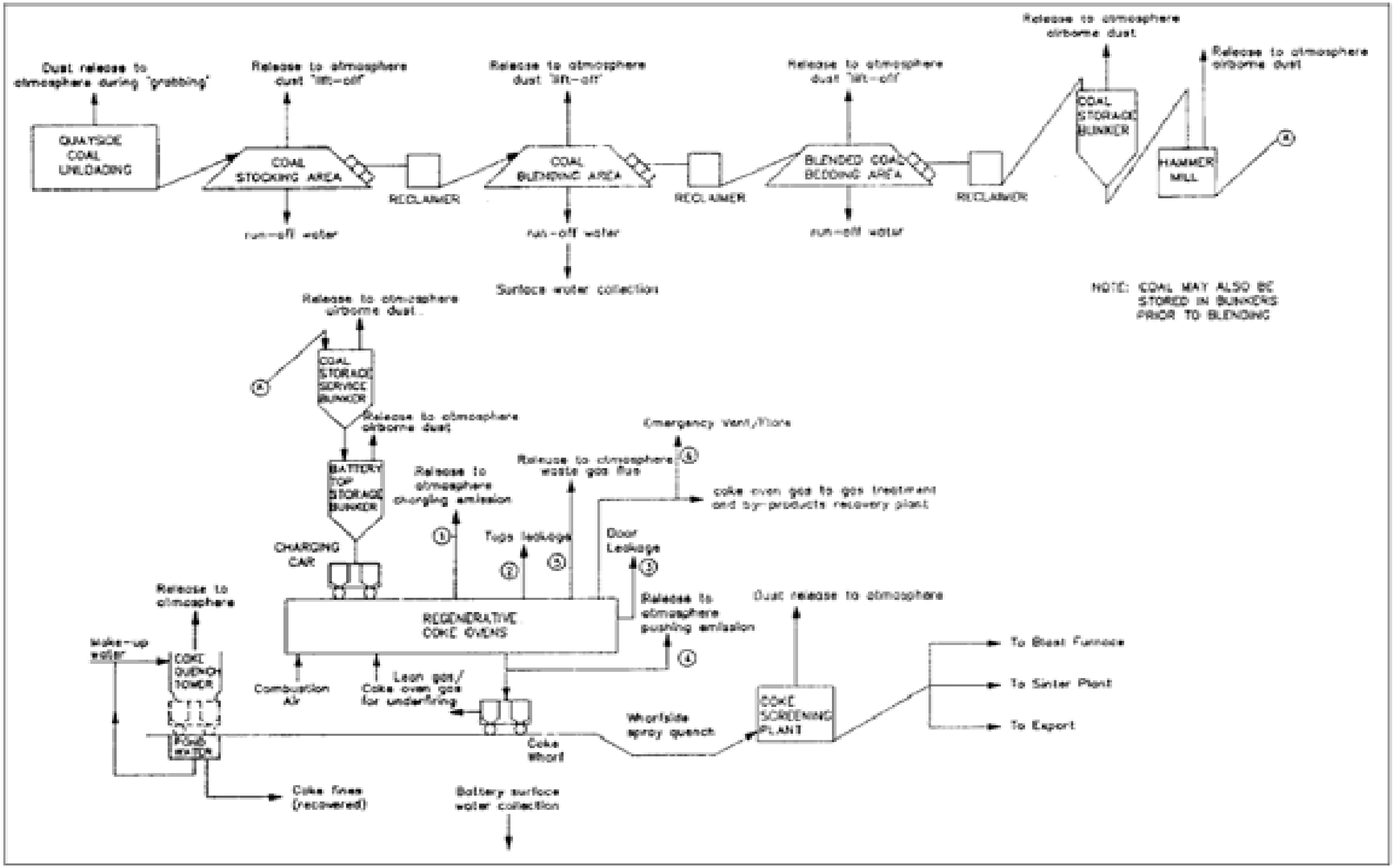
- Only certain coals, for example coking or bituminous coals, with the right plastic properties, can be converted to coke and, as with ores, several types may be blended to improve blast furnace productivity, extend coke battery life, etc.

2. Productive Cycles

A coke oven battery showing the chambers, the coal tower and the coke oven gas collecting main.

2. Productive Cycles

Typical flow diagram of a coke oven plant showing emission sources – [UK Coke, 1995]



2. Productive Cycles

Blast Furnaces

- The first true coke-based blast furnace was introduced in 1735.
- The blast furnace remains by far the most important process for the production of pig iron.
- The technique is likely to continue to dominate pig iron production for at least the next 20 years [Lüngen, 1995].

General view of two blast furnaces with three hot stoves each and the stack for the waste gas from the hot stoves

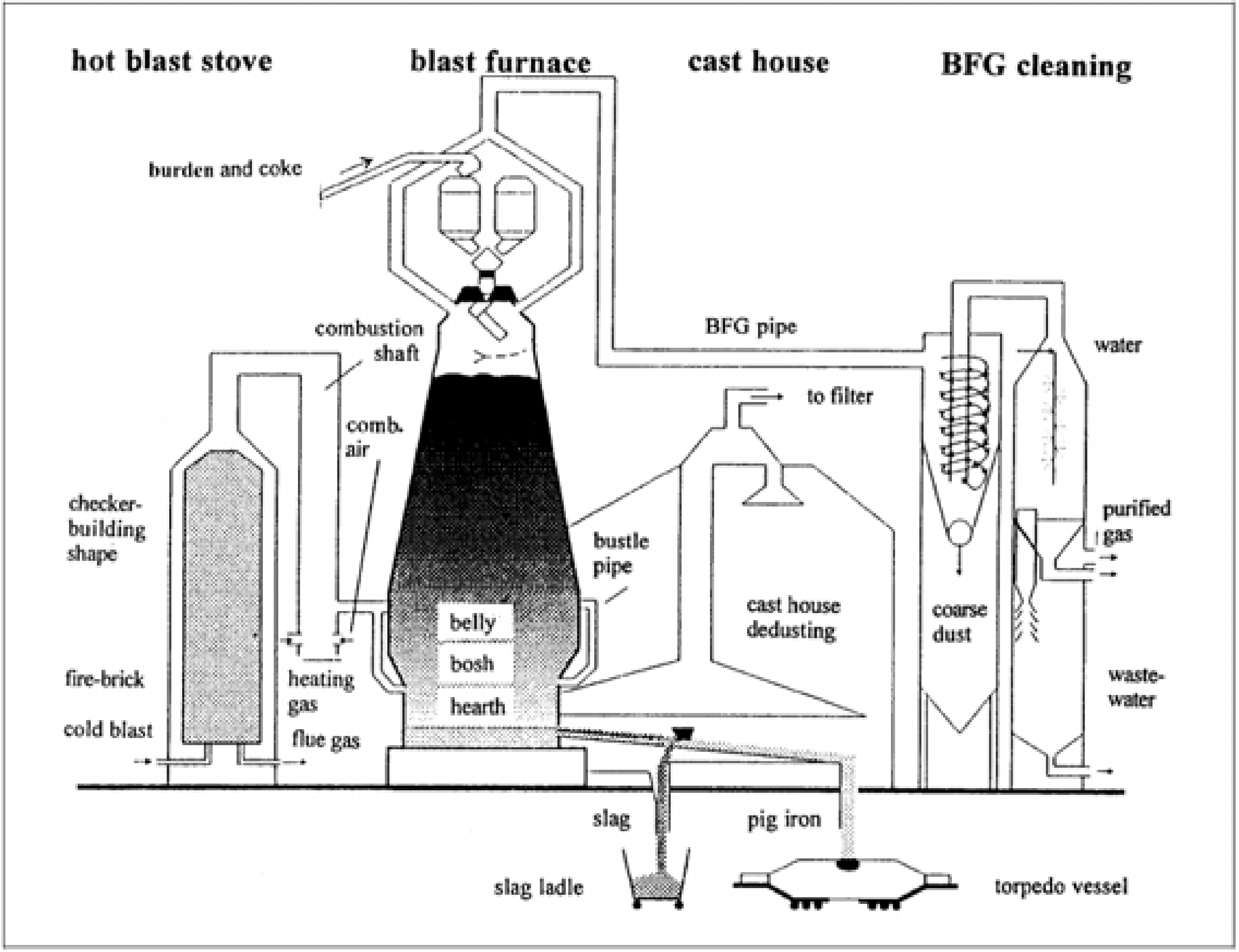
2. Productive Cycles

Blast Furnaces

- A blast furnace is a closed system into which iron bearing materials (iron ore lump, sinter and/or pellets), additives (slag formers such as limestone) and reducing agents (coke) are continuously fed from the top of the furnace shaft through a charging system that prevents escape of blast furnace gas (BFgas).

- Next figure shows a simplified layout of a blast furnace consisting of the furnace itself, the cast house, the hot stoves and two-stage treatment of Bfgas:

Simplified scheme of a blast furnace - [UBA Rentz, 1996]



2. Productive Cycles

Basic oxygen steelmaking and casting

- The replacement of air with oxygen in steelmaking was originally suggested by Henry Bessemer.
- Since 1950, Oxygen has been used in steelmaking irrespective of the specific production method.
- A prerequisite for the cost-effective use of the basic oxygen furnace (BOF) process on an industrial scale was the availability of the required tonnage of technically pure oxygen, as well as the water-cooled lance technology necessary for introducing the oxygen into the converter.

2. Productive Cycles

Basic oxygen steelmaking and casting

- The BOF process and the electric arc furnace (EAF) have since replaced less energy efficient existing steel making processes such as the Thomas process and open-hearth process (Bessemer, Siemens-Martin).
- The BOF process and the electric arc furnace are the only processes being used to produce steel in the EU.
- The BOF process accounts for two thirds of production and the EAF process for the remaining third (EU 15 in 1996).

2. Productive Cycles

Basic oxygen steelmaking and casting

Basic oxygen furnace at the moment of charging hot metal

2. Productive Cycles

Electric steelmaking and casting

- The direct smelting of iron-containing materials, such as scrap, is usually performed in Electric Arc Furnaces (EAF) which play an important and increasing role in modern steel works concepts.
- Today the percentage of electric arc furnace steel of the overall steel production in the EU are 35.30%.
- In Italy and Spain the production of electric arc furnace steel is significantly higher than steel production via the blast furnace-basic oxygen furnace route.

2. Productive Cycles

Electric steelmaking and casting

- The major feed stock for the EAF is ferrous scrap, which may comprise of scrap from inside the steelworks (e.g. offcuts), cut-offs from steel product manufacturers (e.g. vehicle builders) and capital or post-consumer scrap (e.g. end of life products).
- Direct-reduced iron (DRI) is also increasingly being used as a feedstock due both to its low gangue content and variable scrap prices.
- As in the BOF, a slag is formed from lime to collect undesirable components in the steel.
- Next Figure shows an electric arc furnace plant. The building containing a twin shell EAF is totally enclosed in order to minimise dust, gaseous and noise emissions.

2. Productive Cycles

Electric steelmaking and casting

2. Productive Cycles

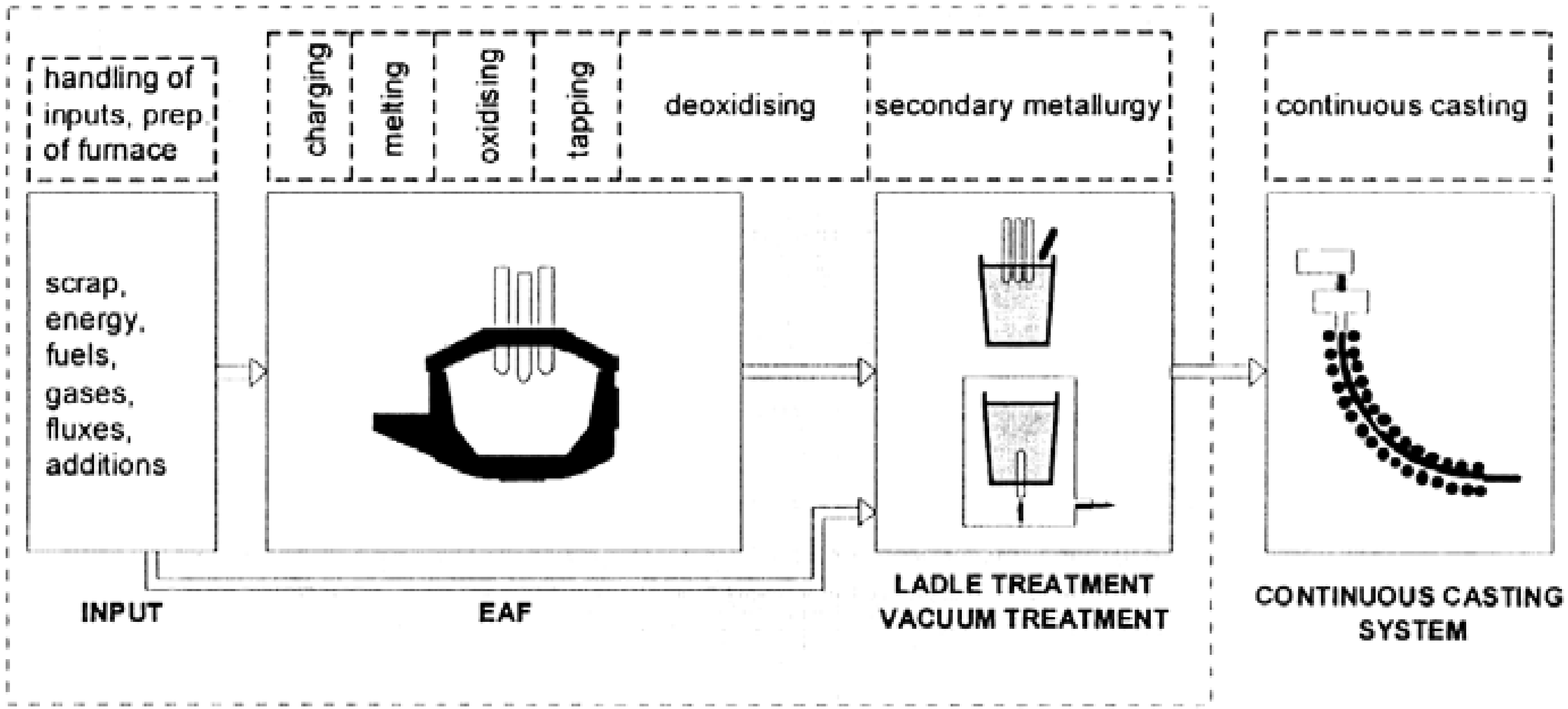
Electric steelmaking and casting

Electric arc furnace with three electrodes and a shaft for scrap charging

2. Productive Cycles

Electric steelmaking and casting

Overview of the processes related to electric arc furnace steelmaking - [D Rentz, 1997]



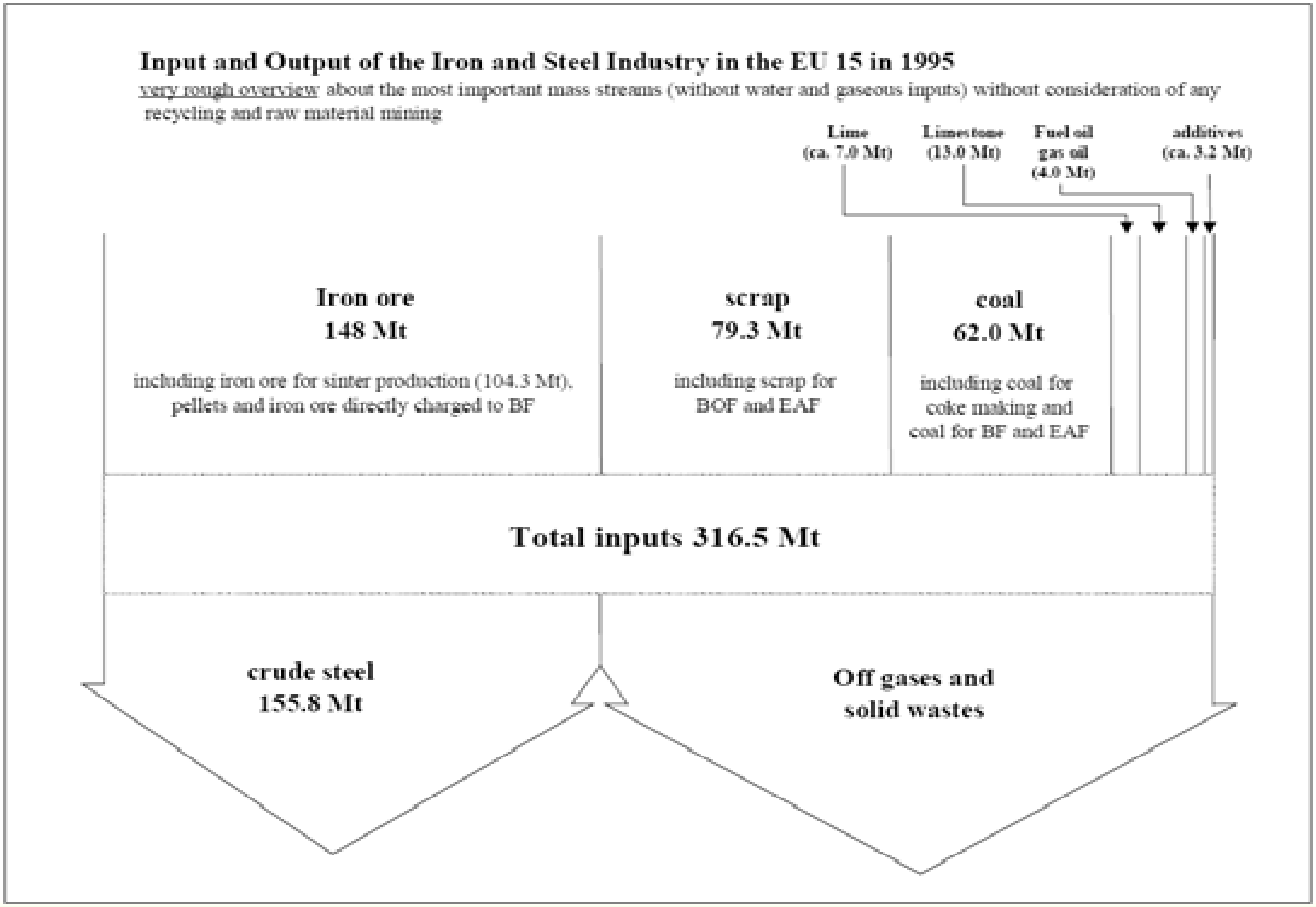
3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

- The iron and steel industry is highly intensive in both materials and energy.

- A simplified input/output scheme illustrating and numbering the main input mass streams together with the quantity of crude steel produced in the EU 15 in 1995 is shown below:

3. Main environmental issues



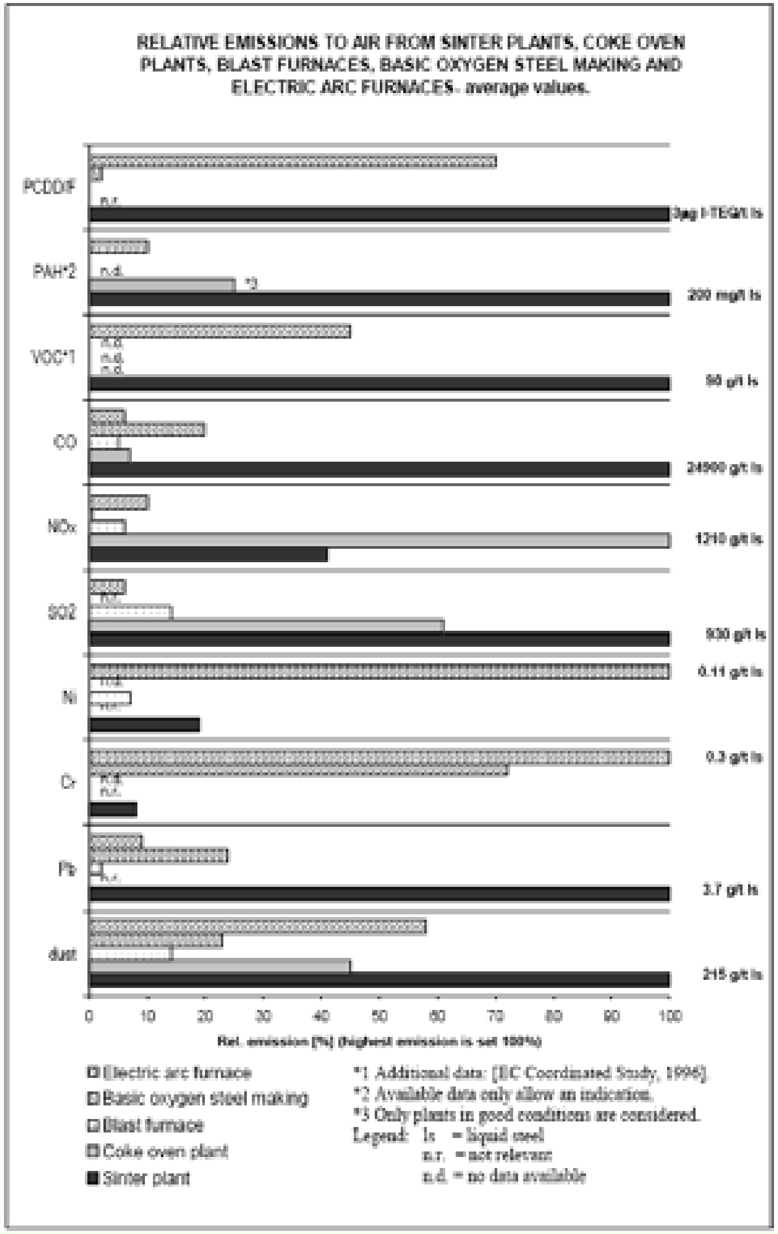
3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

- Important subject for action in response to environmental concerns are generally considered to relate to controlling air emissions and managing solid waste.

- Air pollution remains an important issue

- In integrated steelworks, sinter plants dominate the overall emissions for most atmospheric pollutants, followed by coke-oven plants.



3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

- A relative value of 100% is assigned to the type of plant giving rise to the highest emission for each individual pollutant
- Blast furnaces, basic oxygen steelmaking, coke ovens as well as electric arc furnaces have considerable relative percentages of dust emissions.
- The gaseous emissions from electric-arc furnace steelmaking can be relevant for mercury and for the organic pollutants.

3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

- The first steps towards air pollution control were taken with dust collection and removal.
- In the eighties and nineties dust removal has become increasingly effective (especially secondary dedusting).
- This has reduced the directly related heavy metal emissions except in the case of those with high vapour pressure such as mercury.
- Efforts to minimise SO2 and NOx emissions have also been made.

3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

- In addition the emissions of organohalogen compounds such as polychlorinated dibenzo-p-dioxins and -furans (PCDD/F), hexachlorobenzene (HCB) and polychlorinated biphenyls (PCB) together with polycyclic aromatic hydrocarbons (PAH) and monocyclic aromatic hydrocarbons, especially benzene, became increasingly important.
- The so-called diffuse emissions from plants and emissions from open yard storage also became subject to control.

3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

- The contribution of the iron and steel industry to the overall emissions to air in the EU is significant for heavy metals and PCDD/F, but less so in the cases of NOx and SO2;
- In the next Table is shown: contribution of integrated steelworks (sinter plants, coke oven plants, blast furnaces, basic-oxygen steelworks) and of electric-arc furnace steel-making to the overall emissions of SO2, NOx , heavy metals and PCDD/F in the EU 15.

3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

Parameter	Year	Emissions in the EU 15 [t/a]	Percentage Contribution of the Iron and Steel Industry [%]
SO_2	1994	12088000*1,2	Ca. 1.5*6
NO_x	1994	12435000*1,2	ca. 1*6
Cd*3	1990	200	19
Cr*3	1990	1170	55
Cu*3	1990	3040	5
Hg*3	1990	250	3
Ni*3	1990	4900	3
Pb*3,4	1996	12100	9*7,8
Zn*3	1990	11100	35
PCDD/F*5	1995	5800 g I-TEQ	19

*1 power generation is not covered
*2 data source: [EEA, 1997]
*3 data source: [TNO Report, 1997]; numbers cover integrated steelworks (sinter plants, coke ovens, blast furnaces, basic oxygen steelmaking and electric arc furnace steelmaking)
*4 data corrected because of recent drastic reduction of vehicle lead emissions, based on [UN-ECE Lead, 1998]
*5 data from [LUA NRW, 1997]
*6 calculated from the emission factors given in chapter 3
*7 with the phaseout of lead in petrol the percentage will increase
*8 the crosscheck with the data given in Figure 1.8 and in chapter indicates, that the percentage is only 4%

3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

- The quantities of solid residues, waste, and by-products are generally high.
- Recycling and reuse has reached fairly high levels but varies greatly across the EU and would benefit from further optimization.
- In the next Table is shown: average specific quantity and average percentage of landfill disposal of solid residues/wastes/by-products from integrated steelworks and from electric-arc furnace steelmaking.

Solid wastes/residues/by-products	specific quantity [kg/t LS][*1]	percent. disposed of on landfills [%][*2]
sinter plants[*3]		
• dust	0.9-15	?
coke oven plants[*4]	-	-
blast furnaces		
• Cast house dust	?	?
• dust and sludge from BFgas purification	14	33
• slag	280	2
pig iron desulphurisation	9 - 18	41
basic oxygen steelmaking		
• coarse dusts and sludges from BOF gas treatment	3-12[*8]	42
• Fine dusts and sludges from BOF gas treatement	9-15[*8]	12
• converter slag	99	26
• slags from pig iron ladle, mixer, steel ladle and tundish	34	9
• slags from secondary metallurgy	11[*5]	?
• dismantled refractories	6	76
electric arc furnace		
• slag		
• carbon steels	129	69
• low alloyed steels	109	59
• high alloyed and stainless steels	161	34
• dust from furnace and building evacuation	15[*6]	63[*6]
continuous casting	4 - 6	-[*7]

*1 used conversion factors (weighted average of all European basic oxygen steelworks): 940 kg pig iron/t LS
*2 the residual percentage is recycled within the works or used externally
*3 dusts from sinter strand, cooler and building air dedusting are normally fully recycled to the strand except some cases in which the dust from the last field of the electrostatic precipitator is disposed to landfill; in case of application a fine scrubber the sludge from wastewater treatment is also disposed to landfill (in Europe only very few cases)
*4 the by-products benzene, tar, naphthalene, sulphuric acid, elementary sulphur are fully recycled/reused
*5 average from three basic oxygen steelworks
*6 average for carbon, low alloyed and high alloyed/stainless steels
*7 mill scale normally is recycled to the sinter plant
*8 from [EUROFER BOF, 1997]

all data from [EC Study, 1996], unless stated otherwise. Average values shown.
Legend: LS = liquid steel; BF = blast furnace; BOF = basic oxygen furnace

3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

- Wastewater discharge from coke oven plants is of significant higher relevance than discharges from the water circuits at blast furnaces, basic-oxygen steelmaking, and continuous casting plants.
- Noise emission, local soil pollution as well as groundwater pollution are other matters of concern for the iron and steel industry.
- The energy consumption is considerable.
- The specific energy consumption for 1 t liquid steel, produced via the coke oven/sinter plant/blast furnace route is about **19.3 GJ** calculated according to [Lüngen, 1995; Peters, 1994]. This amount is dominated by the coal input.

3. Main environmental issues

Environmental relevance of the Iron and Steel Industry

- It also includes the consumption of electricity, which is about **1.6 GJ/t LS** (the electricity consumption itself has been multiplied by *factor three* to make it comparable with primary energy).

- The specific energy consumption for the production of electric arc furnaces steel is about **5.4 GJ/t LS**. The electricity consumption has also been multiplied by *factor three*.

3. Main environmental issues

Storage and handling of raw materials

- Primary iron and steelmaking involves high input mass streams of raw materials such as ores, pellets, scrap, coal, lime, limestone (in some cases also heavy oil and plastics) and of additives and auxiliaries.
- These materials are usually transferred to the site in bulk carriers by road, rail or water transport.
- Both these and the intermediate products, such as coke and sinter, have to be stored on stockyards or silos and transported to the individual processing plants, usually by conveyor belt.

3. Main environmental issues

Storage and handling of raw materials

- Wind-borne dust from the stockyards and conveyor belts, including transfer points, can be a significant source of emissions.
- When material including leachable compounds and such as hydrocarbons from mill scale or scrap, is stored in unpaved stockyards attention also has to be paid to soil and ground water pollution and to run-off water.

3. Main environmental issues

Storage and handling of raw materials

In an integrated steelworks, the individual units are connected both in terms of product flows and internal flows of ***residues*** (mill scale, filter dusts, sludges from scrubbing BFgas or BOF gas etc.), ***water*** (common treatment of various wastewater streams, cascade usage of cooling water, etc.) and ***energy*** (COG, BFgas, BOF gas, steam from BF top pressure turbines or basic oxygen furnaces etc.).

3. Main environmental issues

- These interdependencies have been installed in order both to minimize emissions and to optimize productivity and reduce costs.

Energy

- ***Energy*** interdependency is the most complex of these interdependencies.
- The dominant energy inputs are coal and, if bought from an external supply, coke.
- Also electricity, natural gas, oil and (in a few cases) plastics represent the energy inputs.

3. Main environmental issues

Energy

- Coke oven gas (***COG***), blast furnace gas (***BFgas***) and basic oxygen furnace gas (***BOF gas***) are used for many purposes (heating coke oven batteries, provision of hot blast, ignition of the sinter feed, heating furnaces for hot rolling etc.).
- Steam from top pressure turbines of the blast furnaces or from basic oxygen furnaces is also used for various processes.
- COG and BFgas are recovered and used at all integrated steelworks.

3. Main environmental issues

Energy

- This is not the case for BOF gas or for steam recovery using BF top pressure turbines. Steam recovery is dependent on top pressure of the blast furnace, on the operation condition of the BOF and the usability of BOF gas.
- Approximately 88% of the imported energy is ultimately derived from coal, 83% of which is converted into coke.
- Blast furnaces consume about 60% of the overall energy demand of the steelworks, followed by rolling mills (25%), sinter plants (about 9%) and coke ovens (about 7%).

3. Main environmental issues

Solid Residues/by-products

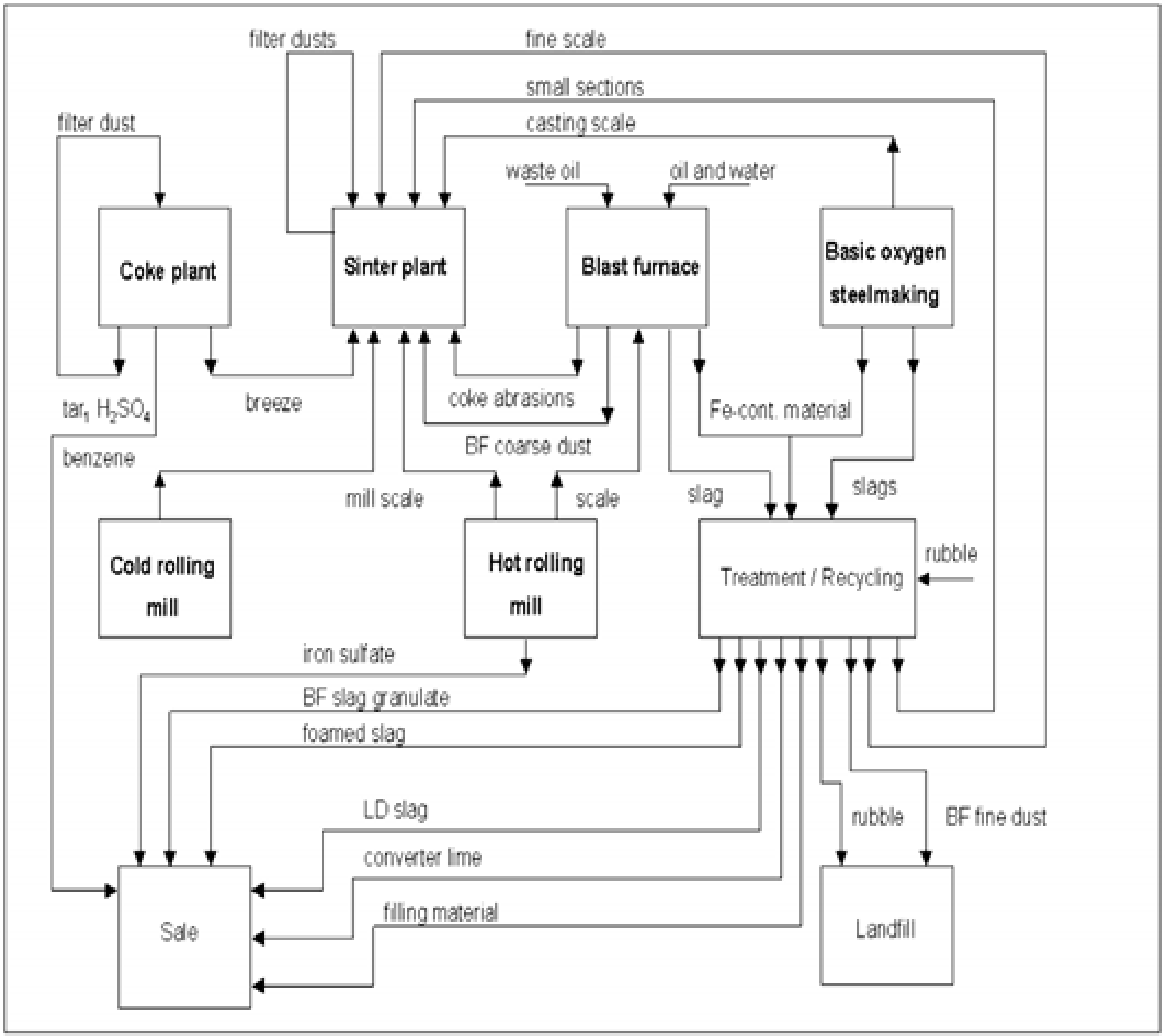
- The management of residues is characterized by advanced techniques for extracting value from the various types of slag and by recycling of most of the residues in the sinter plant, which can be considered the 'digester of an integrated steelworks'.
- The sinter plants plays this important role of recycling residues for which no adequate alternatives exist.
- Only small parts of the overall quantity of residues are landfilled.

3. Main environmental issues

Solid Residues/by-products

- This often consists of fine dust from blast-furnace gas (BFgas) cleaning, rubble, fine dust from basic oxygen furnace (BOF) gas scrubbing (if wet cleaning is used) and, in some cases, the high alkali chlorides and heavy metal chlorides from the last field of electrostatic precipitators treating the off-gas from sinter strands.

- Next figure gives a typical example of the management of by-products and residues in an integrated steelworks:


filter dusts
fine scale
small sections
filter dust
casting scale
waste oil
oil and water
Coke plant
Sinter plant
Blast furnace
Basic oxygen steelmaking
tar, H_2SO_4
breeze
coke abrasions
Fe-cont. material
benzene
BF coarse dust
mill scale
scale
slag
slags
Cold rolling mill
Hot rolling mill
Treatment / Recycling
rubble
iron sulfate
BF slag granulate
foamed slag
LD slag
converter lime
filling material
rubble
BF fine dust
Sale
Landfill

3. Main environmental issues

Water

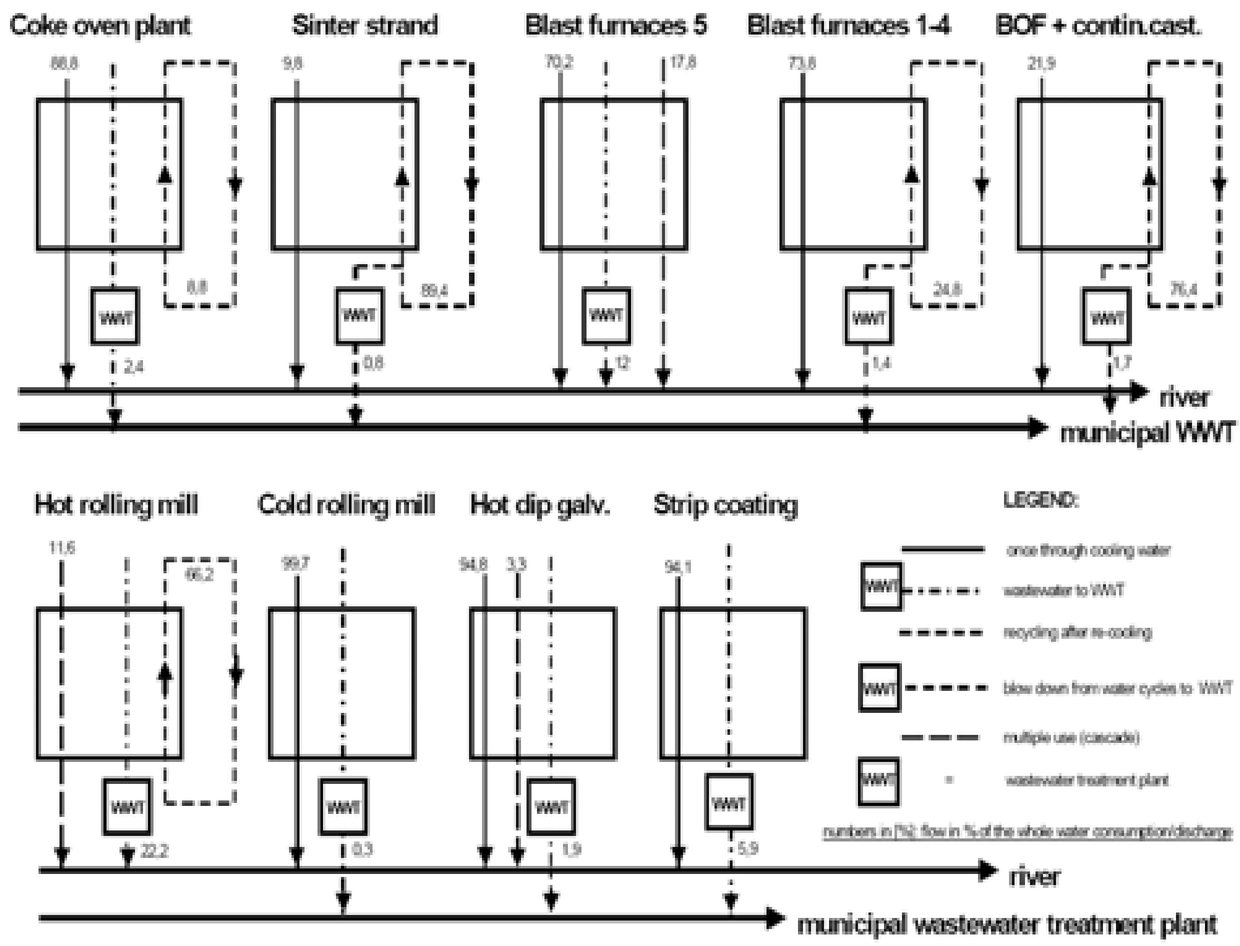
- The water management in an integrated steelworks primarily depends on the local conditions, above all on the availability of fresh water and on legal requirements.
- Legal restraints would tend to focus on minimizing discharges of cooling water and materially polluted wastewater but there are also cases where the authorities demand the avoidance of plumes from re-cooling towers, which prevents further cooling water recycling.

3. Main environmental issues

Water

- Next figure gives an example of water management with an indication of the water treatment of an integrated steelworks with surplus of intake water availability, thus explaining the presence of many once-through cooling systems, resulting in a specific water consumption of more than 100 m3/t steel.
- At sites with very low fresh water availability there is a need to save water as much as possible. In such cases the specific water consumption can be less than 10 m3/t steel, and sometimes less than 5 m3/t steel, in which case the interdependencies are much more intensive.

Water Management of an Integrated Steelworks - example (numbers in flow-%)



4. Conclusions

The iron and steel industry is a highly material and energy intensive industry. More than half of the mass input becomes outputs in the form of off-gases and solid wastes/by-products. The most relevant emissions are those to air. Those from sinter plants dominate the overall emissions for most of the pollutants. Although big efforts have been made to reduce emissions, the contribution of the sector to the total emissions to air in the EU is considerable for a number of pollutants, especially for some heavy metals and PCDD/F. The rate of reuse and recycling of solid wastes/by-products has been increased dramatically in the past but considerable amounts are still disposed to landfills.

5. References

Best Available Techniques

Reference Document on the Production of Iron and Steel

- December 2001-

http://eippcb.jrc.es/pages/FActivities.htm
(Iron and Steel Production, BREF 12.01)