Report on Best Available Techniques (BAT)
in the
Electric Steelmaking Industry

FINAL DRAFT

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Glossary

AC	Alternating Current
AOX	Organic Halogen Compounds
BAT	Best Available Techniques
BImschG	Federal Immission Control Act (Bundesimmissionsschutzgesetz)
BF	Blast Furnace
BOD	Biological Oxygen Demand
BOF	Basic Oxygen Furnace
BSW	Badische Stahlwerke GmbH
ChemG	Chemicals Law (Chemikaliengesetz)
COD	Chemical Oxygen Demand
DC	Direct Current
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace(s)
EBT	Eccentric Bottom Tapping
EC	European Community
EEC	European Economic Community
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EU	European Union
FCCC	Framework Convention on Climatic Change
FRG	Federal Republic of Germany
GMH	Georgsmarienhütte GmbH
HELCOM	Helsinki Commission
IISI	International Iron and Steel Institute
IPPC	Integrated Pollution Prevention and Control
IPPC-D	Directive on Integrated Pollution Prevention and Control
KrW-/AbfG	Federal Recycling and Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz)
LAI	Committee of the Federal States for Immission Control
MVA	Mega Volt Ampere
n.a./ n.d.	Not available/ Not detectable
OECD	Organisation for Economic Co-operation and Development
OSPAR	Paris and Oslo Commission
PARCOM	Paris Commission
PSAG	Preussag Stahl AG
STP	Standard Pressure Temperature
TA	Technical Instructions (Technische Anleitung)
TE	Toxic Equivalent
UBA	German Federal Agency for the Environment (Umweltbundesamt)
UHP	Ultra High Power
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
VAI	Voest Alpine Industrieanlagenbau
VDEh	Verein Deutscher Eisenhüttenleute e.V.
VOC	Volatile Organic Compounds
WHG	Federal Water Act (Wasserhaushaltsgesetz)
WHO	World Health Organization

Chemical Symbols

Al_2O_3	Aluminium oxide
As	Arsenic
C	Carbon
CaO	Calcium oxide, lime
Cd	Cadmium
Cl	Chlorine
C_nH_m	Hydrocarbon
CO	Carbon monoxide
Co	Cobalt
CO_2	Carbon dioxide
Cr	Chromium
Cr_2O_3	Chromic oxide
Cu	Copper
CuO	Cuprous oxide
F	Fluor
Fe	Iron
FeO	Iron oxide
H_2O	Water
HCl	Hydrogen chlorine
HF	Hydrogen fluoride
Hg	Mercury
K_2O	Potassium oxide
KCl	Potassium chloride
Mg	Magnesium
MgO	Magnesium oxide, magnesia
Mn	Manganese
MnO	Manganous oxide
Mo	Molybdenum
Na_2O	Sodium oxide
NaCl	Sodium chloride
Ni	Nickel
NiO	Nickel oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen (x) oxide
P_2O_5	Phosphorous pentoxide
Pb	Lead
PCDD/ PCDF	Dioxin/furan
S	Sulphur
SO_2	Sulphur dioxide
SO_x	Sulphur oxide
Se	Selenium
SiO_2	Silica, silicon dioxide
Sn	Tin
TiO_2	Titanium dioxide
Tl	Thallium
V	Vanadium
V_2O_5	Vanadium pentoxide
Zn	Zinc
ZnO	Zinc oxide

Units

a	year
µm	micro metre
°C	Degree Celsius
dB(A)	decibel acoustic
kg	kilogram
kWh	kilowatt hour (3.6 MJ)
m	metre
m^2	square metre
m^3	cubic metre
mg	milligram
min	minutes
ng	nanogram
t	ton

Executive Summary

About the document

The goal of this study is to provide background information for the determination of Best Available Techniques (BAT) with respect to integrated environmental protection within the electric steelmaking industry to support the Technical Working Group Iron and Steel (TWG, cf. below). It gives information on the environmental performance of modern German electric steelmaking plants and identifies the impact of particular environmental protection techniques and also of relevant production techniques on this performance. The paper bases mainly on literature study, but also on technical discussions with experts and information collected at plant visits. Figures mentioned within the paper represent in most cases the performance of German plants. The study is funded by the German environmental protection agency (Umweltbundesamt) and has been carried out by the French-German-Institute for Environmental Research (University of Karlsruhe). It was distributed in a co-ordination process to several German and European institutions, which commented on the paper (cf. 8.4).

Legislative framework

On September, 24th, 1996 the Council of the European Communities issued the Directive 96/61/EC on Integrated Pollution Prevention and Control (IPPC-D) [19]. This Directive aims to achieve a high level of protection of the environment taken as a whole. Article 16.2 urges the Commission to organise an exchange of information between Member and the industries concerned on BAT for certain industrial activities. For this reason, an Information Exchange Forum (IEF) has been established to facilitate the information exchange. To consult the IEF with respect to specific technical information on industrial activities mentioned in Annex 1, IPPC-D, Technical Working Groups (TWG) already have been established for some sectors. These TWG will exist for all relevant industrial activities listed in Annex 1, which inter alia contains installations for the secondary fusion of steel with a capacity exceeding 2.5 tonnes per hour (Annex 1, 2.2). The members of the TWG support the working group with their expertise in the corresponding industrial sectors. The results of the information exchange process on BAT are written down in BAT Reference Documents (BREF).

Contents of the document

The document contains information on inputs and outputs of electric steelmaking plants and on techniques to influence these material flows. Most of the secondary steel is produced in electric arc furnaces (EAF). For this reason, the study puts the main emphasis on determining BAT for electric arc steelmaking. Figure 1 gives an overview of the processes and the related inputs and outputs, that are explicitly considered in this study.

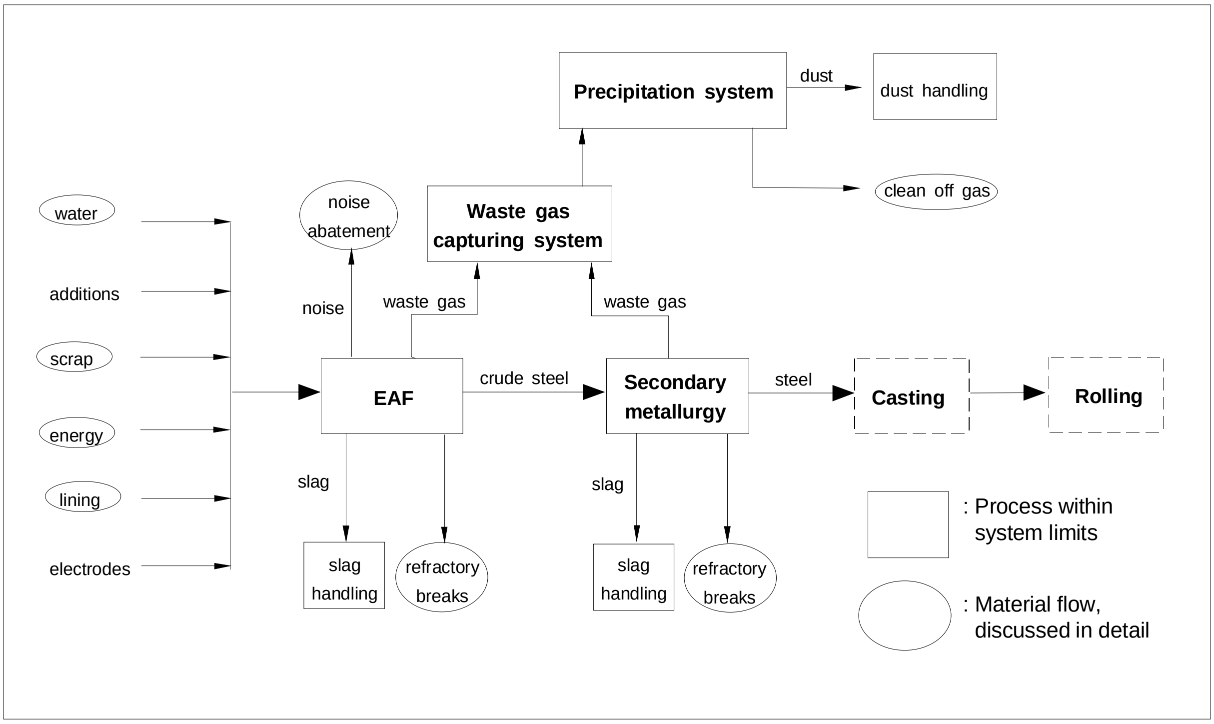


Figure 1: Schematic overview of the steelmaking process via the secondary route

The study provides a detailed description of the secondary steelmaking process via the EAF route. This includes in a first step the description of relevant sub-processes and related input/output levels. In a second step, available techniques for integrated pollution prevention and control and their effects on the environmental performance of the steelmaking process are presented. To complete the list of available techniques and to show possible future developments, also so-called emerging techniques are mentioned, which may be considered available within a certain period of time. This summary contains an overview of the list of candidate BAT and their qualitative performance on environmentally relevant fields.

In addition to the technical information, also comments on the legal provisions, that apply to EAF steelmaking on a German and on an international level, and general data on the secondary steelmaking industry in Germany are made in this paper.

As a result, the study identifies a set of BAT for steelmaking via the secondary route, according to the aspects that are mentioned within the IPPC-D. On the basis of these techniques, achievable emissions levels into the different media can be established. The proposed set of BAT is included in this summary.

Topics not explicitly covered by the study include odour, vibrations, and monitoring aspects.

Candidate Best Available Techniques

The list of available techniques is grouped into 5 sectors, according to the main field the measures apply to (general aspects including energy, air, soil, water, noise). Table 1 gives a qualitative overview of the effects, the techniques have on the different environmental media.

Table 1: Candidate BAT for IPPC in the secondary steelmaking industry

Techniques/Effects	*Refer-ence mark*	Effect on emissions and consumption of inputs							Collection of process emissions			Abatement of process emissions			Pro-duc-tivity	State of the art	Retro-fit mea-sure	Noise
Material flow, resource		Process emissions			Conspt. intern		Conspt. extern											
Media, resource		**S**oil	**W**ater	**A**ir	**E**nergy	**I**nput	**E**	**I**	**S**	**W**	**A**	**S**	**W**	**A**				
General developments in modern production technology (including energy aspects, cf. 4.3 and 6.1):																		
Developments in general (cf. 4.3.1 and 6.1.1):																		
(Ultra) High power operation	G1	↑		↓		↓									↑	*		↓
Water cooled side walls and roof	G2	↓			↑	↓									↑	*	*	
Oxy-fuel burners and oxygen lancing	G3			↑	↓	↑									↑	*	*	
Eccentric bottom tapping	G4				↓	↓					↓				↑	*		
Foaming slag practice	G5	↑↓			↓	↓									↑	*	*	↓
Ladle or secondary metallurgy	G6			↑↓											↑	*	*	
Automation	G7			↓	↓										↑	*		
Heat recovery of furnace cooling	G8						↓									*	*	
Scrap sorting and cleaning	G9			↓												*	*	
Techniques concerning the medium air (cf. 4.4 and 6.2):																		
Collection of emissions into the air (cf. 4.4.1):																		
Direct extraction of process fumes	A1				↑						↓					*	*	
Hood system	A2				↑						↓					*	*	
Furnace enclosure	A3										↓					*	*	↓
Total building evacuation	A4				↑						↓						*	
Handling of waste gases (cf. 4.4.2 and 6.2.1):																		
Post combustion of waste gases	A5			↓	↑											*	*	
Cooling of waste gases (quenching)	A6			↓	↑											*	*	
Use of energy content (waste gas)	A7				↓											*	*	
Precipitation of particulates (cf. 4.4.3):																		
Electrostatic precipitator	A8				↑							↑		↓		*	*	
Bag filter	A9				↑							↑		↓		*	*	
Techniques concerning the medium soil (cf. 4.5):																		
Treatment of slags (cf. 4.5.1):																		
Use in construction (EAF slag)	S1	↓						↓								*	*	
Processing to lime fertiliser or recycling to EAF (Sec. Metallurgy)	S2	↓						↓								*	*	
Treatment of precipitated dusts (cf. 4.5.2):																		
Recycling of precipitated dusts	S3	↓			↑		↑	↓									*	
Waelz process (commercial steel dust)	S4	↓					↑	↓								*	*	
DK-process (commercial steel dust)	S5	↓					↑	↓								*	*	
Imperial Smelting Furnace	S6	↓					↑	↓								*	*	
Treatment by submerged EAF (high grade steel dust)	S7	↓					↑	↓									*	
Scan dust process (high grade steel dust)	S8	↓					↑	↓									*	
Treatment of refractory breaks (cf. 4.5.3):																		
Refractory breaks treatment	S9	↓				↓										*	*	
Techniques concerning the medium water (cf. 4.6):																		
Treatment of used water:																		
Closed loop system	W1		↓							↓						*	*	
Techniques concerning noise aspects(cf. 4.7):																		
Encapsulation	N1																	↓
Muffling	N2																	↓
Acoustic barriers and further measures	N3																	↓

Within the main document, the effects are further specified and quantitative data is provided. Where available, also examples of German plants employing these techniques have been specified.

Best Available Techniques

In consideration of the first scrutiny, performed in the main document, the following technologies and techniques are proposed to be BAT with respect to integrated pollution prevention and control. Where possible, figures for the levels of achievable emissions have been supplied. It has to be carefully checked on a plant by plant basis for the retrofit measures mentioned, if the proposed BAT are not only reasonable for new plants, but also for existing plants.

General aspects (including energy efficiency):
With respect to the efficiency of use of raw materials and energy, a modern EAF, either equipped with high power or UHP AC or DC technology and a sensible combination of the measures G1-G8 is proposed to be BAT. Waste heat arising at waste gas cooling or furnace cooling should be recovered, if possible, for steam production or district heating.

Air:
Next to process integrated measures like (U)HP operation and automation (G1, G7), which can help to reduce emissions into the air, the following air pollution abatement scheme is proposed: (1) Collection of emissions into the air by the EAF, the secondary metallurgy devices, as well as tapping and charging operations by a combination of the measure A1 and an appropriate selection of the measures A2-A4, such that on no significant amount of emissions is released to the environment (and additionally the working staff in the furnace area is not subject to hazardous concentrations of dust, heavy metals and other substances). (2) Post combustion and quenching of the waste gas to support a complete combustion of the waste-gas and to prevent a de-novo synthesis of PCCD. (3) Gas cleaning by means of fabric filters, i.e. a bag house, to achieve to the greatest possible extent the lowering of the clean gas dust content and a minimisation of PCDD and PCDF.

Soil:
Slags should be treated for re-use, most likely in the construction area. While an almost complete use of EAF slags seems to be possible, the re-use potential of slags arising at secondary metallurgy processes has to be checked on a plant by plant basis. For the handling of precipitated dusts a recovery of the metal content of the dusts is proposed. This can be performed by a suitable recovery process for both, commercial and high grade steel dusts. Options for the handling of refractory breaks need to be evaluated on a plant by plant basis.

Water:
The only relevant use of water in an electric steelmaking plant within the scope of this study is for cooling purposes. For this use, a closed loop cooling system for the EAF is proposed to be BAT. Additionally, some water may also be used for gas cooling or secondary metallurgy. Requirements for possible discharges by these processes are presented within the main document.

Noise:
Noise emitted by electric steelmaking plants should be muffled in such an adequate way.

Actual reference values and comments on further aspects are provided in the main document.

1 Preface

Remark:

The goal of this study is to provide background information on candidate best available techniques for environmental protection within the German electric steelmaking industry. It gives information on the environmental performance of modern German electric steelmaking plants and identifies the impact of certain particular environmental protection techniques but also production techniques on this performance. The paper mainly bases on literature study, but also on technical discussions with experts and on information collected at plant visits. It was distributed in a co-ordination process to several German and European institutions, which commented on the paper (cf. 8.4). Figures mentioned within the paper represent in most cases the performance of German plants.

On September, 24th, 1996 the Council of the European Communities issued the Directive 96/61/EC on Integrated Pollution Prevention and Control (IPPC-D) [19]. This Directive aims to achieve a high level of protection of the environment taken as a whole. It was enacted especially considering the common environmental goals of the EC, laid down in article 130r, EC-treaty (conservation and protection of the environment and improvement of environmental quality (i), protection of human health (ii), sustainable use of resources (iii), promotion of measures on an international level to handle regional or global environmental problems (iv)), and being aware of the fact that the implementation of an integrated concept of pollution prevention needs to be addressed by measures on a community level.

Annex I of Directive 96/61/EC contains an extensive list of industrial activities, which the Directive applies to. According to this list, also industrial activities related to the production and processing of metals are subject to the measures within the IPPC-D (N° 2). The Directive provides a general framework with principles for integrated pollution prevention and control. Pollution is defined to be "*the direct or indirect introduction as a result of human activity of substances, vibrations, heat or noise into the air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment*". The goal of this integrated concept is to protect the environment taken as a whole by preventing and controlling emissions into all environmental media: air, water, and land.

The necessity for drawing up notes on best available techniques (BAT) for certain industrial activities is constituted by some of the measures laid down within the Directive:

- First of all, Article 16 2. demands explicitly an exchange of information on best available techniques: "*The commission shall organize an exchange of information between member states and the industries concerned on best available techniques* ..." [19]. Furthermore, the IPPC-D obliges the member states to provide the EC-commission with representative data and possibly information on BAT for the categories of industrial activities listed in Annex I (art 16 1.). The member states also have to ensure that the competent authorities follow or are informed of developments in best available techniques (art 11).

Within the IPPC-D the concept of BAT is defined the following way:

- BAT "*shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole* ..." (art 2.11).

The term BAT is used at several places in the IPPC-D. It is employed to specify dynamic requirements with respect to integrated pollution prevention and control. Requirements, where the notion of BAT is used, include the following provisions:

- The definition of basic obligations, that operators of industrial activities have to comply with (art 3, esp. 3 a).
- The definition of a permit procedure, according to which permits shall be granted only if operators fulfil a number of requirements, further specified in the Directive (art 3, 6, 7, 8).
- The reminder to the competent authorities, that a permit has to include emission limit values for at least a minimum number of substances explicitly named in Annex III. These emission limit values, or possibly equivalent parameters or technical measures, shall be based on reference values derived from so-called *Best Available Techniques* (*BAT*, art 9 4.). The operators are obliged to use BAT, however, these may differ from the BAT described within the BAT Reference documents (BREF). Nevertheless, the performance of other techniques has to achieve at least the same level of prevention and control than the techniques mentioned within the BREF..
- The requirement for the EC-member states to ensure compliance with these basic obligations by the operators (art 3, 4, 5).

The corresponding articles dealing with the definition of best available techniques and those demanding an exchange of information on BAT are the motive for this document (in particular art 16 2.).

The Council of the European Union will finally set emission limit values based on a proposal of the Commission for sectors and polluting substances, that have been specified within the

Directive, and for which a need of Community action has been identified. The proposal is, in particular, based on the information exchange specified in Article 16, i.a. dealing with BAT. As an instrument of control, the implementation of the Directive and its effectiveness in comparison to other Community environmental instruments shall be documented in reports according to Article 16 3.

The purpose of this document is to identify BAT for the sector secondary steel production[1] (cf. Annex I, 2.2, IPPC) and so to support the information exchange on BAT. To perform this task, the basic intentions of the IPPC-document have to be considered, i.e. to take account of the integrated approach in environmental protection. Integrated approach means to take into consideration all environmental media at the same time in order to protect the environment as a whole. Minimisation of releases into one medium may result in only a shift of pollution from one medium to another. Annex IV names a list of considerations to be taken into account generally or in specific cases when determining BAT. Inter alia,

- the use of low-waste technology,
- the use of less hazardous substances,
- the furthering of recovery and recycling of substances generated and used in the process, where appropriate,
- the nature and volume of the emissions concerned,
- the consumption and nature of raw materials (including water) and energy used in the process and their energy efficiency,
- the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it

should be considered, always having in mind the likely costs and benefits of measures and the principles of precaution and prevention (cf. Annex VI).

Article 3 defines the basic obligations of the operators. Installations must be operated in such a way that:
"*(a) all the appropriate preventive measures are taken against pollution, in particular through application of the best available techniques; (b) no significant pollution is caused; (c) waste production is avoided [...] ; where waste is produced, it is recovered, or, where that is technically and economically impossible, it is disposed of while avoiding or reducing any impact on the environment; (d) energy is used efficiently; (e) the necessary measures are taken to prevent accidents and limit their consequences; (f) the necessary measures are taken*

[1] In the context of this paper steelmaking via the blast furnace/converter route is considered to represent primary steelmaking and steelmaking in electric arc furnaces secondary steelmaking (cf. chapter 3.2.1).

upon definitive cessation of activities to avoid any pollution risk and return the site of operation to a satisfactory state."

This paper describes available techniques for the integrated pollution prevention and control for the secondary iron and steel industry in Germany and determines BAT with respect to the goals and principles laid down in the IPPC-Directive.

The structure of the document is as follows:
Chapter 2 gives general information about the iron and steel industry, including an overview of relevant legislation in Germany and on an EU-level. Then in Chapter 3 basic information about the applied processes and techniques in the secondary iron and steel industry is provided, and related typical input/output levels are investigated. Chapter 4 contains a list of candidate best available techniques, i.e. techniques that are possible BAT candidates. In chapter 5 best available techniques with respect to integrated pollution prevention and control are determined. A selection of so-called *emerging techniques*, i.e. promising novel pollution prevention and control techniques, is presented in chapter 6. The following chapter 7 gives conclusions and recommendations. Finally, more detailed information on selected topics is provided in the Annex (chapter 8).

2 General Information

This chapter aims to provide basic information on the German steel industry, in particular the secondary steel industry, mainly with respect to economic (2.1) and regulative (2.2) aspects.

2.1 General information on the secondary iron and steel industry

Total steel production in Germany amounted to 42 million tons in 1995 (40 million t in 1996), thus contributing a considerable share to the world steel production of 753 million tons (1995). Revenues achieved by sales of iron containing products like pig iron, raw steel, and ferroalloys amounted to 39 billion DM in 1995 [100].

The total output and relative share of steel produced via the secondary, or that is to say electric steelmaking route, has continuously increased in Germany within the last 20 years from 12.6% in 1975 (5 million tons) to 24.1% in 1995 (10.143 million tons), while the total production of steel has remained the same or even decreased at times. Compared to European (34.9%) and world-wide (32.6%) averages in 1995, though, a potential still seems to exist for a relative and an absolute increase in production. Figure 2-1 depicts the development of the total steel production in Germany from 1977 to 1995, subdivided into steel production processes.

Figure 2-1: Steel production in Germany according to technologies

Source: [100]

In Germany, locations of the secondary steelmaking industry are spread out over most of the federal states (cf. Figure 2-2). Electric steel plants have been built next to or even replacing locations of the traditional steel industry, i.e. integrated steelworks, but also at new locations close to consumers and resources (eg. scrap and energy) [44]. This development is part of a world-wide tendency towards the construction of so-called "minimills", i.e. production plants, in which scrap is melted by means of electric furnaces and following cast by continuous casters [86].

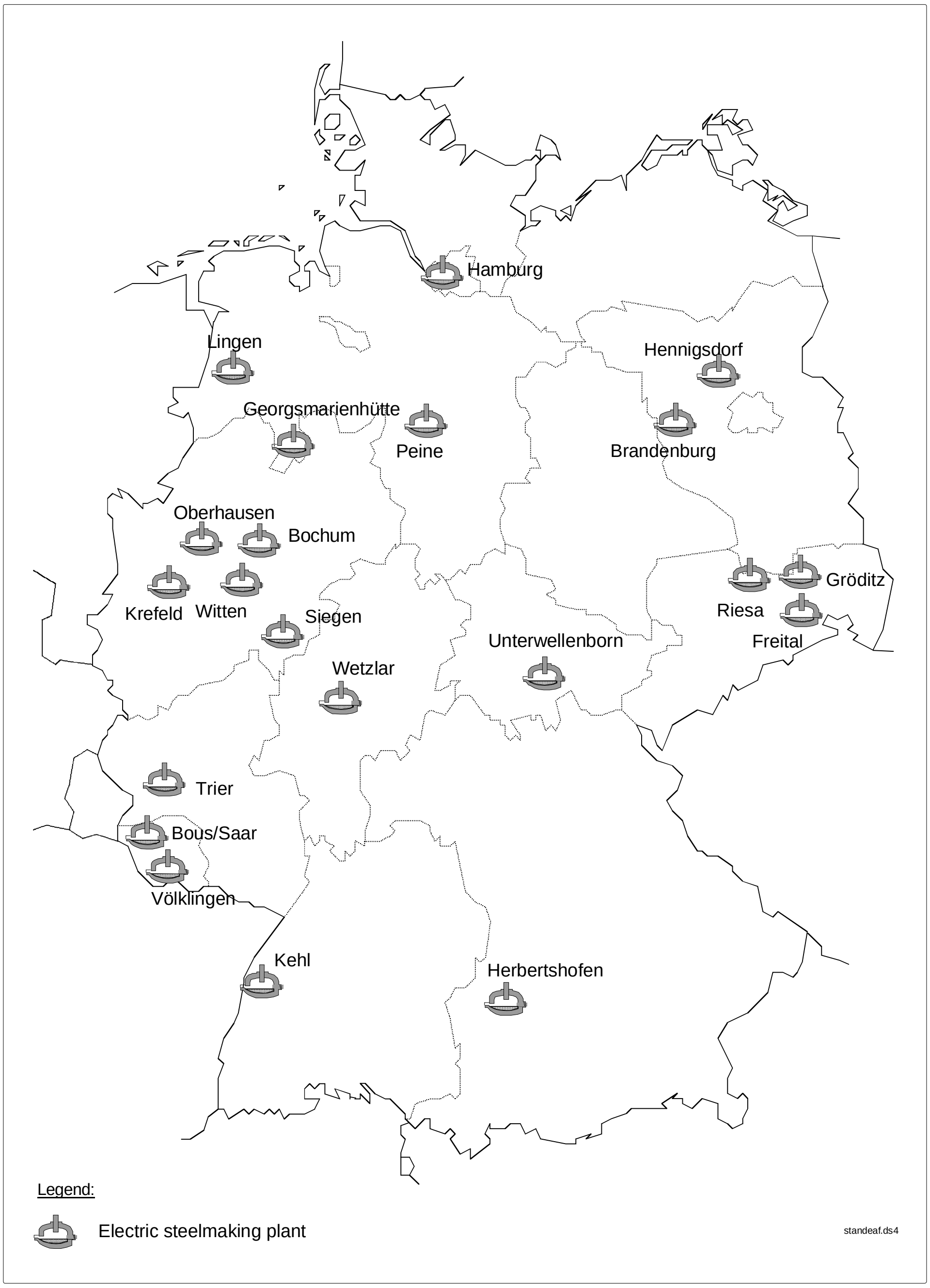


Figure 2-2: Electric steelmaking plants in Germany

Source: following [79]

In general, minimills are highly competitive in comparison to integrated steelworks, since much lower amounts of capital are needed, and also there is a high labour efficiency. For a long time, it was a competitive advantage for integrated steelworks exclusively being able to produce high grade steels. But due to technical developments also electric steel plants are able to produce steel satisfying higher demands for quality, nowadays. Table 2-1 provides a list of examples of electric steelmaking plants in Germany.

Table 2-1: Electric steelmaking plants in Germany (examples)

Company	**Location**	**EAF in plant**	**Capacity [ton]**	**Mainly high grade steel**	**Mainly commercial steel**	**Since**
Ispat-Hamburger Stahlwerke GmbH	Hamburg	1	110		x	1978
Preussag Stahl AG	Peine	1	100		x	1995
Georgsmarienhütte GmbH	Georgsmarienhütte	1	125	x	x	1994
Stahlwerke Lingen GmbH	Lingen	1	85	x		1974
H.E.S. Henningsdorfer E-Stahlwerk GmbH	Hennigsdorf	2	each 85		x	1994/ 1995
Brandenburger E-Stahlwerke GmbH	Brandenburg	2	each 125		x	1986/ 1994
Stahlwerk Oberhausen GmbH	Oberhausen	1	135		x	1979
Krupp Thyssen Nirosta GmbH	Bochum Krefeld	1 1	140 80	x x		1982 1955
Krupp Edelstahlprofile GmbH	Siegen	1	140	x		1978
Edelstahlwerke Buderus AG	Wetzlar	1	100	x		1995
ESF Elbestahl Feralpi GmbH	Riesa	1	70		x	1994
Gröditzer Stahlwerke GmbH	Gröditz	1	35		x	1968
Saarstahl AG	Völklingen	1	125		x	1977
Edelstahl Witten-Krefeld GmbH	Witten	1	110	x		1981
Stahlwerke Thüringen GmbH	Unterwellenborn	1	120		x	1995
Badische Stahlwerke GmbH	Kehl	2	each 85		x	1968/ 1976
Lech Stahlwerke GmbH	Herbertshofen	2	each 65		x	1972/ 1975
Sächsische Edelstahlwerke GmbH Freital	Freital	1	40	x		1986

Source: [93, 95]

Steel scrap is a major input for electric steelmaking plants. This fact itself is of environmental concern, as a world-wide use of 400 million tons of scrap saves up to 635 million tons of ore to be mined, processed, transported, and smelted [39]. In 1995, German electric arc furnace plants used 9.885 million tons of scrap [94], originating from different sources. Generally, scrap can be distinguished by origin and age. So-called plant scrap arises during production and further processing of crude steel within plant limits, both at integrated steel works and at electric steelmaking plants. New scrap arises during the manufacture of finished products, while old scrap denotes scrap returning after utilisation of finished products [39]. Electric steelmaking plants use scrap of various grades and qualities, usually consisting of a mix of old, new, and plant scrap, dependent on the quality of steel to be produced.

2.2 Current legislation relevant for the secondary iron and steel industry

The following section gives a brief overview of current legislation for electric arc steel production plants on an European and a national (German) level. Existing regulations lay down standards for:

- air quality,
- water quality,
- waste management and disposal of hazardous materials.

Further information on international regulations (mainly HELCOM, PARCOM, LRTAP, Basel Conventions) and more detailed information on German legislation is provided in the Annex.

2.2.1 Regulations on an European level

Current European legislation, which is relevant for electric arc steel production plants is listed below:

- EC Directive 84/360/EEC on abatement of air pollution caused by industrial plants, requiring adoption of "Best Available Technology Not Entailing Excessive Costs",
- EC Directive 76/464/EEC on pollution caused by dangerous substances discharged into the aquatic environment,
- EC Directives 75/442/EEC and 78/379/EEC, modified by 91/156/EEC, on waste management;
- EC Directive 85/337/EEC on environmental impact assessment (EIA),
- EC Directive 82/501/EEC concerning hazards to local population outside the limits of the plant in certain specific conditions ("Seveso" Directive).

Based on the 84/360/EEC of 28 June 1984, the European Commission has forwarded a number of Best Available Techniques documents. Two of them concern the secondary iron and steel industry:

- Techno-economic study on the reduction measures, based on Best Available Technologies, of water discharges and waste generation from the primary and secondary iron and steel industry. Final report: September 1993.
- Technical note on the Best Available Technologies to reduce emission of pollutants into the air from electric arc steel production plants. Final Report: April 1994.

2.2.2 Regulations on a German level

The obligations of the EC Directives are implemented into the legislation of the Federal Republic of Germany (FRG) in accordance with the particular administrative procedures. In general, no specific environmental statutes are related to the iron and steel sector, but the industry is mentioned explicitly in some legislative documents.

Important regulations relevant for electric arc steel production plants in Germany are laid down in the BImSchG (Federal Immission Control Act), the WHG (Federal Water Act) and the KrW-/AbfG (Federal Recycling and Waste Management Act). Germany uses a segregated media permitting system for different environmental media, but the final decision about an application is reached on the assessment of environmental impacts to all media by the local authorities. Also noise requirements are considered in the permitting procedure. Germany aims at favouring pollution prevention in the permitting procedure. The „precautionary principle“ has a legal status which enables the standard setting. The legal standards are not subject to any negotiation in the permitting process in Germany.

In compliance with the federal structure of Germany, the implementation of environmental laws and decrees is under the responsibility of the federal states (Bundesländer), which may implement the administrative procedure differently. For new plants, that are regarded as relevant with respect to emissions and releases into the environment, also an environmental impact assessment is required during the licensing procedure (cf. Gesetz über die Umweltverträglichkeitsprüfung UVPG).

2.2.2.1 German regulations concerning the air quality

The basic law for air pollution control and noise abatement is the Federal Immission Control Act (Bundes-Immissionsschutzgesetz BImSchG). It is principally a regulation for the medium air, but it also protects the media water and land in case pollution is introduced via the air. A concept similar to the one of BAT is the definition of the „state of the art technology“ in the Act.

The BImSchG is specified by 21 ordinances and the Technical Instructions on Air Quality (TA Luft). Especially the TA Luft further specifies the requirements to be met by installations subject to licensing. It prescribes limit values for virtually all air pollutants as well as structural and operational requirements designed to limit diffuse emissions. The German Länderausschuß für Immissionsschutz (LAI) issued a model administrative regulation with respect to solid residues resulting from plants subject to the BImSchG, defining technical options to handle these residues [62]. A more detailed description of German regulations concerning the air quality is provided in the Annex.

2.2.2.2 German regulations concerning the water quality

In the case of water management, each discharge, wherever it is located, has to comply with the Federal Water Act (Wasserhaushaltsgesetz WHG) [37], which is the legal instrument, analogous to the BImschG for air pollution control. The WHG is in force for waste water generated by various industrial processes, including the iron and steel industry. The use of surface, coastal, and ground waters requires the approval of the competent authority. The water protection legislation is implemented by the Ordinance on the Industrial Sources of Water and by general administrative regulations concerning minimum requirements to be met by discharges, irrespective of the quality of the receiving medium. In general, the frame regulations for water protection are provided on a federal level, but the federal states complete the water legislation. For further details, see the Annex.

2.2.2.3 German regulations concerning the waste management and disposal of hazardous materials

The legislation for waste was ruled in the Act on Waste Prevention and Treatment (Abfallgesetz: AbfG) [38]. It is applied to the use and storage of waste, i.e. substances to be disposed of by the processor or whose proper treatment is necessary to protect the environment. Additional requirements refer to waste from certain commercial enterprises.

Legislation laying down measures aiming towards „avoidance, utilisation and disposal“ of waste is set down in the Recycling and Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz: KrW-/AbfG) [36] which came into force in October 1996 and supersedes the AbfG. It broadens the entire national waste concept and sets new priorities with regard to the avoidance of and the duty to utilise waste. Moreover, the KrW-/AbfG codifies the manufacturer’s product responsibility [64].

For the administration, the technical guidelines for waste (TA Abfall) [3] and for municipal waste (TA Siedlungsabfall) [4] are important. Furthermore, an administrative instruction, technical guideline on special wastes (TA Sonderabfall), regulates the handling of special waste. Facilities for treating waste have to fulfil requirements regulated in special decrees, based on art. 5 BImSchG.

3 Applied processes, techniques and corresponding input/output levels in the secondary steel industry

3.1 Introduction

Integrated pollution prevention and control requires the consideration and prevention and/or minimisation of all harmful impacts on the environment caused by industrial activities at the same time. Also the shifting of pollution within environmental media has to be avoided.

The goal of the IPPC-Directive (IPPC-D) is to prevent or control pollution caused by certain industrial activities, including steelmaking via the secondary route (cf. art 1 and Annex I). As mentioned in the preface of this paper, it therefore requires the member states of the EU, inter alia, to exchange information about BAT for these activities. Within the IPPC-D pollution is defined to be "the direct or indirect introduction as a result of human activity, of substances, heat or noise into the air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment" (cf. art 2.2). To achieve its goal the Directive lays down measures "to reduce emissions in the air, water and land from the abovementioned activities, including measures concerning waste" (cf. art 1).

Summarising the provisions of the IPPC-D it can be concluded, that the identification of BAT for the secondary steel industry requires an investigation of the underlying production system with particular respect to the emission of substances, heat, and noise caused by the system into the environmental media air, water, and land. Furthermore the considerations of Annex IV, IPPC-D, have to be taken into account, in particular the requirements of Annex IV.9 (consumption and nature of raw materials and energy efficiency of the processes).

This Chapter 3 of the study gives a description of processes and techniques applied to produce steel via the secondary steelmaking route. It also provides some data about typical input/output levels for the processes examined. The chapter is set up in two parts. The first part defines the scope of the study and deals with general aspects of electric steelmaking and the second part investigates relevant system components with respect to input/output levels in a more detailed way.

3.2 Scope of the study

3.2.1 Primary versus secondary steel industry

A distinction between the primary and secondary steel industries with respect to origin and type of the iron-containing material (iron ore or scrap) and important production processes applied (blast furnace/basic oxygen furnace (BOF), electric furnace) is not possible in a clear-cut way. The two major methods for producing steel, electric steelmaking and steelmaking in the BOF, interchangeably use scrap and pig iron as iron-containing materials, at least to a certain extent.

The understanding of the secondary steel industry within the study is derived from the point of view, that steelmaking via the blast furnace/BOF route represents primary steelmaking and the related industry the primary steel industry. The term secondary steel industry in the context of this paper refers to the industry producing steel by means of electric furnaces. The distinction occurs whilst being aware of the fact that nowadays pig iron or direct reduced iron (DRI) are also charged as iron containing inputs into electric furnaces. For example, in Germany Ispat-Hamburger Stahlwerke are charging an 115 t electric arc furnace with an average share of 25% DRI, reduced in a Midrex reduction plant, mainly to produce steel wire [82]. Alternative ways to produce crude steel are not considered.

Almost a 100% of the electric steel in Germany and more than 90% world-wide is produced in electric arc furnaces [101, 75]. For this reason this study focuses on electric steelmaking in *electric arc furnaces* (EAF), supplying raw material for rolling mills, forging or tube plants.

3.2.2 Basic description of steel production via the EAF route

This section gives a brief overview of the basic steps needed to produce steel in electric arc furnaces.

In the steelmaking process that uses the EAF, the primary raw material is ferrous scrap, which is melted using electric energy. Additional inputs are fluxes and additions like deoxidants or alloying elements. The desired product from the EAF process, including secondary metallurgy processes, is crude steel. Next to these main output also a couple of other outputs arise (like slag, particulate emissions, waste gas). Principally, the steelmaking process via the EAF route comprises the following steps:

- Handling of inputs and preparation of the furnace,
- Charging,
- Melting,
- Oxidising (decarburisation),

- Tapping,
- Deoxidising (refining), and Secondary metallurgy.

The prerequisites for the production of electric steel are the provision of the inputs scrap, additions, fluxes, and electrical energy, as well as the regular preparation of the furnace, i.e. its lining with different types of refractory material to protect the furnace shell against high temperatures and chemical and physical strain caused by inputs, heat, and slag.

The charging of the furnace is usually performed in batches: Two or three buckets with, possibly sorted, scrap are inserted through the open top into the furnace in succession to use the capacity of 80-150 ton/heat of modern furnaces.[2] Each charge is partly melted while the next bucket is prepared. Some systems also permit continuous scrap charging, however, in Germany usually charging by means of buckets is applied. According to the desired steel quality, fluxes (eg. lime) and additions (eg. carbon, chromium) are also added. The addition of these materials can take place both during the charging step and the oxidation step, if the furnace is equipped accordingly. To melt the charged inputs, the movable roof is closed, the graphite electrodes[3] (introduced through the roof) are lowered, the electric arcs are ignited, and the melting phase starts. At the hottest spots temperatures up to 3,500 °C arise in the furnace during the melting process. To lower the consumption of electrical energy and to accelerate the melting process, oxygen or a fuel-gas mixture can be injected by special types of lances or by oxy-fuel burners to generate process heat.

The oxidation step normally starts after the melting is completed. It mainly aims to reduce the carbon content of the heat and to oxidise undesired tramp elements. During the melting and the oxidation phase a slag is formed on top of the heat. The slag helps to remove tramp elements like sulphur, silicon, phosphor, and manganese. Besides this positive metallurgical effect, a foamy slag on top of the melt is also important for achieving an efficient energy transfer and in particular the protection of the furnace shell. Another positive effect of the foamy slag is a reduction in noise caused by the EAF process. Usually, at the same time as the injection of oxygen, also pulverised coal, or so-called foaming coal, is injected by lances into the furnace to intensify the boiling. Stirring and bath agitation may also be supported by the injection of inert gases (eg. argon or nitrogen) by means of tuyeres [49].

The tapping step starts with the tilting of the furnace to tap the slag, as the highly oxidised slag is not desired in the following secondary metallurgy processes. Then the raw steel is

[2] The capacity range of modern furnaces (in Germany) is between 10 tons up to 150 tons [102], some recently built furnaces (internationally) melt up to 200 tons [95].

[3] Dependent on the applied technology (DC/AC), there may be one or three graphite electrodes in use.

tapped at temperatures of about 1,600 to 1,680 °C. The tapping angle required to almost empty the furnace varies from 12° to 42°, depending on the tapping system. In practice, eccentric bottom tapping (EBT) is commonly used nowadays. This system allows a slag free tapping and tapping angles of about 12°, which are favourable for cost savings (caused by the reduction of tap-to-tap times, reduction of heat losses, shorter power cables) [50].

In general, secondary metallurgical processes, eg. in a ladle furnace, follow the tapping step. Some refining may also take place in the EAF itself, but nowadays the fine adjustment of the desired steel quality is not performed in the EAF. The secondary metallurgical treatment of the steel melt in an extra vessel was established for the increasing demands on the steel quality, requiring additional post-melting treatment, and the possibility of reducing tap-to-tap times by using the EAF only for the melting of steel.

3.2.3 System limits

Figure 3-1 gives an overview of the steps necessary for electric steelmaking. The dotted frame contains the system investigated. Inputs used and emissions generated within these limits, causing direct or indirect impacts on the environment, are within the scope of the study. This means the identification of BAT refers to those environmental impacts, that are caused by material flows and production steps within the above mentioned units, or sub-processes (handling of inputs/preparation of furnace up to secondary metallurgy processes), and can be influenced by means of certain techniques.

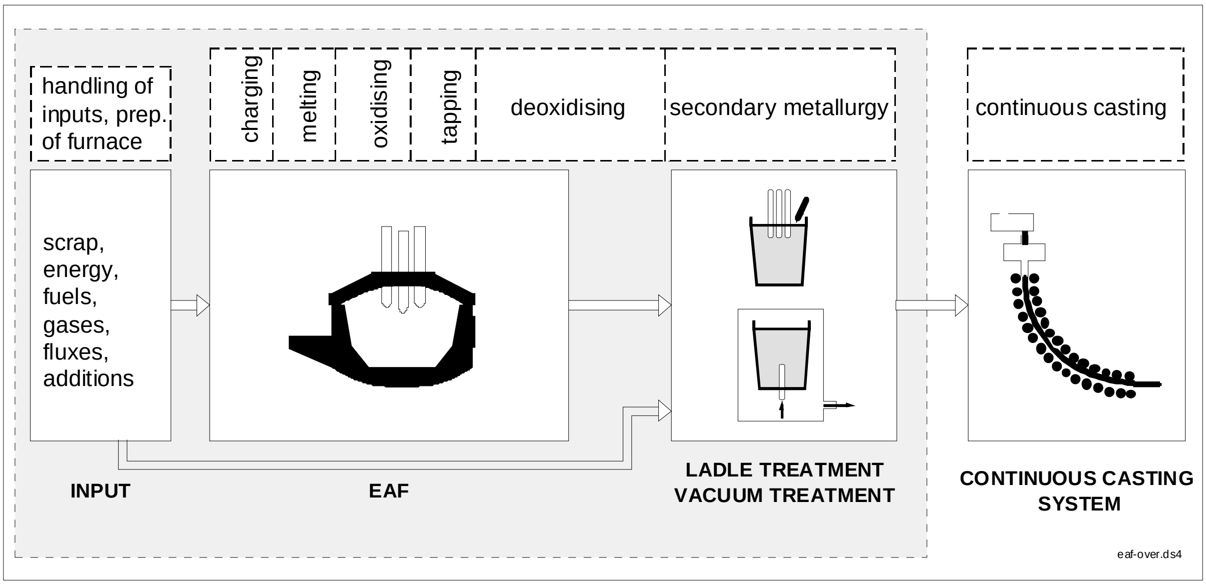


Figure 3-1: Overview of the processes related to electric steelmaking

3.2.4 Discussion of important parameters

The results obtained in the following depend considerably on the type of product and plant investigated, therefore the relevant parameters will be discussed briefly.

3.2.4.1 Generic plant

As already mentioned above, the plant structure considered to be representative comprises the *installations* for the *preparation* and *handling* of the *inputs*, an *EAF*, and equipment for the *secondary metallurgy* treatment. Furthermore it is assumed, that the plants looked at are equipped with installations for the *collection* and *abatement* of emissions into the air, installations for the *treatment of releases*, or wastes into the soil (eg. slags, precipitated dusts), and, if needed, installations for the *treatment of waste water*. The size and the production technology of the plants are deciding factors concerning the relations between inputs, outputs, and emissions, as they determine shifts in efficiency, inter alia for economies of scale. For this reason, the size, or capacity (in tons), and the installed specific power supply (in MVA/t) of the according units are also considered, if necessary.

3.2.4.2 Steel grades

The desired steel quality is a relevant factor for any resulting impacts of electric steel production on the environment, as different types of steel grades require different input compositions and generally different treatments cause changes in the yield and chemical composition of dusts and slags. The study distinguishes the wide spectrum of producable steel grades via the EAF route into two relevant categories:

- Commercial steels (carbon steels),
- High grade steels, including high alloyed steels and special steels like stainless steels.

Whenever necessary and available, different data for the two groups of steel grades will be provided.

3.2.4.3 Existing plants versus new plants

There may be differences in the reasonableness to use different techniques in existing plants in contrast to new plants. The differences in recommendations for best available techniques with respect to existing or new plants will be pointed out and explained, if necessary.

3.2.4.4 Definition of the terms primary, secondary, direct and fugitive emissions

For purposes of this paper important terms are defined in the following. In this study the term *direct emissions* denotes emissions, that are produced in the electric arc furnace during the melting and possibly during the refining periods in the secondary metallurgy vessels and are collected by capturing devices. Source and direction of the arising gas flows are clearly definable. Usually, direct emissions in the EAF are collected by means of direct extraction devices (so-called primary dedusting systems, emissions are also referred to as *primary emissions*), or so-called secondary dedusting systems like hoods or enclosures. The collected emissions are then conducted to a gas cleaning facility. The term *secondary emissions* includes direct emissions arising and captured during scrap handling, charging, heat tapping, and slag tapping captured by means of hoods or enclosures (cf. chapter 4), whereby the source and direction of secondary emissions are not as clearly defined as in the case of primary emissions. The origin and direction of *fugitive emissions* is not defined and they are not captured.

3.3 Inputs and releases caused by processes related to the EAF

Processes related to the EAF unit are charging, melting, oxidising, tapping, and deoxidising (cf. Figure 3-1). As these processes are all directly connected to the EAF, it is reasonable to draw up an input/output balance only for the whole unit, and not for each single process. Also the releases connected to the provision and handling of the inputs are considered in this section. Figure 3-2 shows the relevant input/output relations to be taken into account. In addition, selected technologies for the controlling of releases are indicated. Inputs for the production of electric steel in the EAF are:

- Iron containing materials, usually ferrous scrap,
- Electrical energy,
- Further energy (oxygen, natural gas),
- Furnace lining,
- Graphite electrodes,
- Fluxes (lime, coal, that also serves as an energy source),
- Additions (possibly alloys, dependent on the desired steel quality),
- Cooling water (depending on the cooling system)
- Inert gases for stirring, if applied.

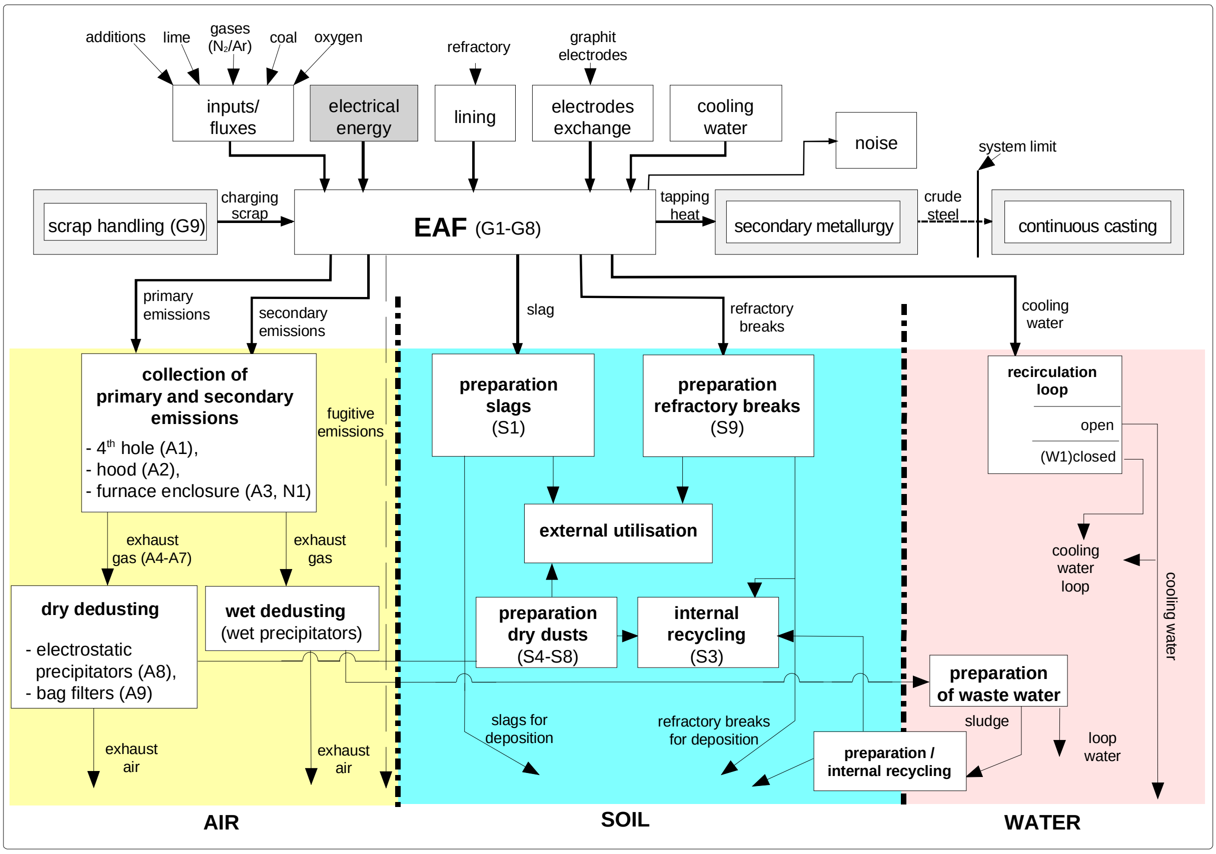


Figure 3-2: Inputs, releases, and selected technologies related to the EAF processes

Table 3-1 provides an input/output balance for EAF plants with ranges for common quantities, if available.

Table 3-1: Specific input/output balance of typical EAF plants

Inputs			Outputs		
Scrap	kg/t	1,080-1,130	**Steel melt**	kg/t	1,000
Total energy	kWh/t	650-750	**Slag**	kg/t	100-150
Of that: **Electrical energy** **Oxygen**	kWh/t m^3/t	345-490 24-47	**Particulates (total precipitated)**	kg/t	10-20
Graphite electrodes	kg/t	1.5-4.5	Of that obtained at:		
Lime	kg/t	30-80	**Primary dedusting**	mg/m^3	3,400-33,900
Coal	kg/t	13-15	**Secondary dedusting**	mg/m^3	150-275
Lining	kg/t on average	1.9-25.1 8.1	**Refractory breaks**	kg/t	n.a.
Water	closed loop		**Plant scrap**	kg/t	n.a.
			Noise	dB(A)	125-139

Source: [87, 98]

Scrap is the major iron containing input for electric arc furnaces. It usually shows an iron-content of 80-100% [69]. About 1,130 kg scrap per ton of crude steel usually are charged into the electric furnace, sometimes the scrap is substituted by sponge or direct reduced iron (DRI). The required energy for the secondary production of steel is mainly supplied in the form of electrical energy. But also electrode burn-off, energy input by oxy-fuel-burners, oxygen lancing, and exothermic reactions (eg. burning of oils and greases or coal) serve as energy sources [57]. To protect the inside of the furnace vessel from wear and tear, inter alia by heat, it is lined with refractory material. These materials are subject to mechanical and thermal stress, as well as chemical attack, necessitating the breaking out of the remaining contaminated material and a new lining of the furnace from time to time [33]. Further comments on energy input and use within an EAF as well as remarks on the lining of furnaces can be found in the Annex.

The desired output of the EAF is crude steel. But next to this main product some additional releases are also emitted from the EAF (cf. chapter 4). The most important outputs into the separate media are emissions into the air during charging, melting, and tapping (primary waste gas dust content ranges from 13,300 to 33,900 mg/m^3 (STP)), as well as solids like slag (100-150 kg/t) or refractory breaks. The use of the medium water depends in principle on the cooling system of the EAF and the type of flue gas cleaning facility. An electric steelmaking plant also emits a considerable amount of noise, typical noise levels for electric arc furnaces, given by the sound power level, are between 125 and 139 dB(A).

Table 3-2 depicts some analyses for the composition of slags arising at the production of electric steel in an EAF.

Table 3-2: Chemical composition of EAF and Secondary Metallurgy (SM) slags

Component [wt.-%]	Commercial EAF [22]	Commercial EAF [34]	Commercial EAF [75]	Commercial EAF [43]	High grade EAF [43]	Ladle slag A [43]	Ladle slag B [43]	AOD slag [43]
Fe_{tot}	28.20	18	10-19	25	<=2	<=2	5	<=1
CaO	27.8	35	35-45	30	45	50	30	50
CaO_{free}	n.a.	n.a.	n.a.	<1	<=10	<=10	<=5	<=10
SiO_2	11.5	15	10-18	15	30	10-20	20	25
Al_2O_3	4.60	6	3-8	5	5	3	10	2
MgO	4.40	8	7-13	5	7	7	10	4
MnO	4.90	5	4-12	5	2	<=1	5	1
Cr_2O_3	1.44	<=1	n.a.	1.5	3	<=0.5	<=0.5	2
TiO_2	0.30	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
P_2O_5	0.64	<=1	<=1	n.a.	n.a.	n.a.	n.a.	n.a.
Na_2O	0.46	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
K_2O	0.11	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
V_2O_5	0.11	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
ZnO	0.02	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CuO	0.03	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
NiO	0.01	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
S	0.02	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
C	0.33	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

A: lime silicate type **B: lime aluminium type**

Other elements, like Pb, As, Sb, Hg, Cl, F, can be found in traces. Furthermore, Table 3-3 provides an exemplary analysis of the raw gas composition of two German electric arc furnaces, that produce commercial steel. The data was measured after the post-combustion chamber and the cooling zone of the furnaces and before the entry of the gas into the bag house. Both furnaces are equipped with water quenches for a rapid cooling of the waste gases. Analyses are provided for both the operation with and without quenching.

Table 3-3: Raw waste gas analysis for selected German electric arc furnaces

Substance	EAF 1		EAF 2	
in mg/m³ (STP)	Normal operation	Water quench	Normal operation	Water quench
Total dust	13,379	2,458	33,875	3,659
Class 1 dust-like inorganic substances				
Cadmium (Cd)	3.5537	2.6032	2.59	0.743
Mercury (Hg)	0.1136	0.1095	n.d.	n.d.
Thallium (Tl)	0.042	n.d.	n.d.	n.d.
Class 2 dust-like inorganic substances				
Arsenic (As)	2.6457	0.7759	6.2418	1.4396
Cobalt (Co)	0.3502	0.0888	0.6677	0.12
Nickel (Ni)	5.6898	0.8556	4.8737	0.803
Selenium (Se)	n.d.	n.d.	n.d.	n.d.
Class 3 dust-like inorganic substances				
Lead (Pb)	338.3697	218.9618	373.4424	102.5526
Chromium (Cr)	44.3373	1.4533	86.9606	10.8096
Copper (Cu)	50.5468	8.5367	62.7648	13.4046
Manganese (Mn)	247.5962	52.9882	425.729	142.8455
Vanadium (V)	2.8437	0.1848	3.9868	0.319
Tin (Sn)	5.4314	1.3739	4.2018	1.1443
Vaporous or gaseous inorganic substances				
Fluor as HF	0.93	0.88	0.24	0.4
Chlorine as HCl	6.2	0.6	3.2	<0.8
Carbon monoxide (CO)	472	259	197	-
Carcinogenic substances				
Benzopyren	0.0001	0.00015	0.00165	0.00009
Dibenzanthracen	0.00007	0.00011	0.00038	0.00004
Benzol	0.073	0.174	0.174	0.045
Organic substances (data is given in ng TE/m³ (STP))				
Dioxins and furans (PCDD/PCDF)	8.11	2.55	17.32	2.58
PCB	0.00132	0.00225	0.00822	0.00074

Source: [97]

3.4 Inputs and releases related to the secondary metallurgy processes

The processes referred to as secondary metallurgy are considered in general as being all the treatments of the steel melt after the tapping step up to the beginning of the casting facilities [11]. The aim of the secondary metallurgy in principle is the adjustment of the desired steel quality. The variety of steel types that can be produced via the EAF route requires different treatments of the melt in order to achieve the desired characteristics. The units generally used for carrying out the secondary metallurgy process are ladle furnaces or converters. Depending on the steel quality desired, different units, or vessels, are used in secondary metallurgy, and thus the required inputs and produced outputs (products, releases) also differ. The purpose of secondary metallurgy has also shifted within its development: Initially, homogenisation, fine adjustment of steel composition, and deoxidation were important aims, whereas nowadays the

- improvement of the degree of purity,
- reduction of non-ferrous inclusions,
- reduction of carbon, sulphur, phosphorus, hydrogen, and nitrogen contents, and
- adjustment of a suitable temperature for continuous casting

are the goals of the secondary metallurgy processes [40]. Figure 3-3 shows possible input/output flows for secondary metallurgy processes in a ladle furnace. Due to the variety of options for secondary metallurgy treatments and the related inputs and outputs, it is not possible to present a table with representative specific inputs and outputs.

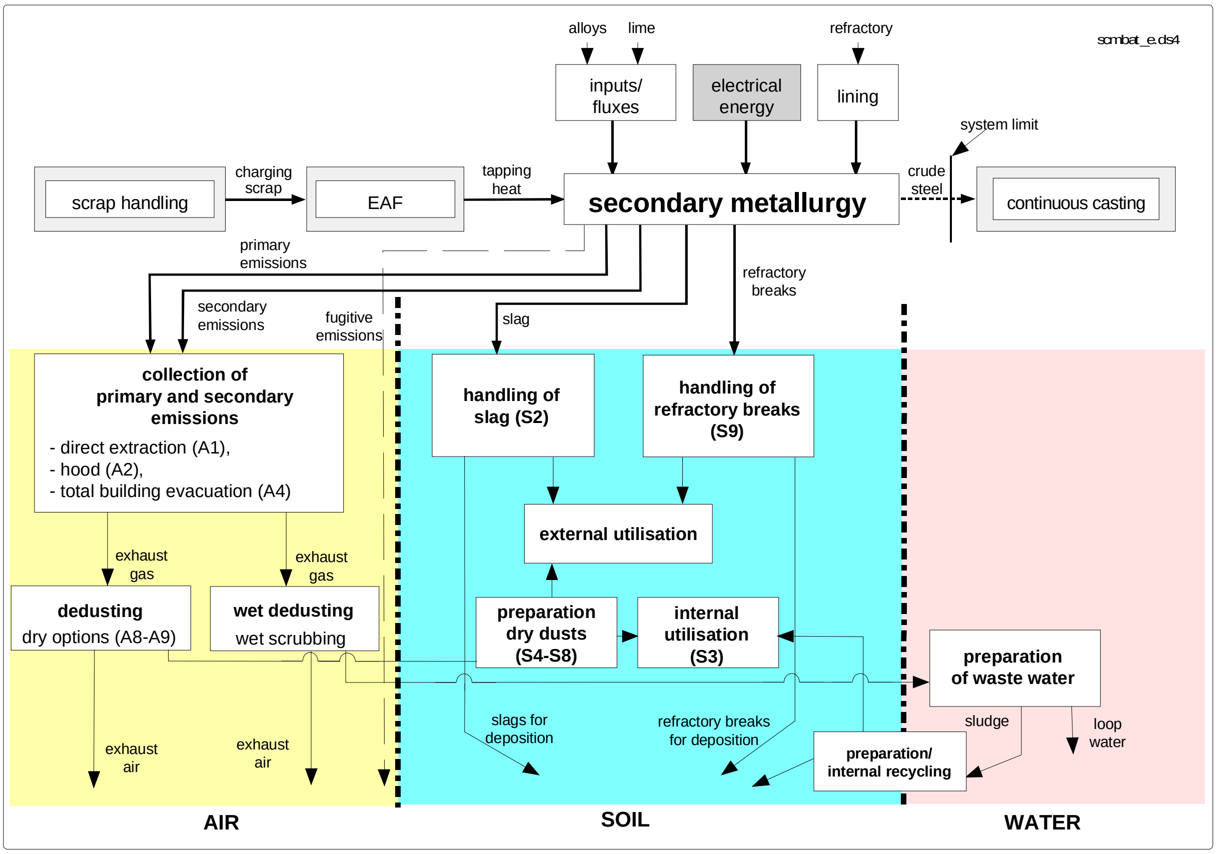


Figure 3-3: Inputs, releases, and selected technologies related to the secondary metallurgy processes

4 Candidate best available techniques for integrated pollution prevention and control in the secondary steel industry

This chapter presents a list of candidate best available techniques for IPPC in German EAF plants, taking the definition of BAT in Art 2.11 IPPC-D as a basis.

4.1 The definition of BAT

"The term ‘best available techniques’ signifies the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole.

‘Techniques’ include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned.

‘Available’ techniques means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator.

‘Best’ means most effective in achieving a high general level of protection of the environment as a whole.

In determining the best available techniques special consideration should be given to the items listed in Annex IV." (Art. 2.11, IPPC-D).

4.2 First scrutiny

Candidate measures for integrated pollution prevention and control presented in this section usually concern more than one environmental medium or one input at a time. The primary intention of a technique, though, usually aims towards the protection of a single sphere[4] (eg. protection of air quality, reduction/use of solid wastes, improvement of energy efficiency or productivity). Table 4-1 gives an overview of modern techniques applied within the secondary steel industry both for production purposes and for environmental protection purposes. Each technique is provided with a reference mark, which helps to identify the according section in the text. The table depicts the qualitative and quantitative tendencies of effects caused by the

[4] Inter alia caused by the fact, that regulations on environmental protection focused on controlling releases into separate media for a long time.

different techniques on the media and on resource consumption, or resource saving (use). All the techniques listed with a reference mark are candidates for BAT. Cross media effects of techniques can be identified by indications of several effects on media or resources. Most of the listed modern techniques are applied within production plants of the secondary steel industry in Germany.

The techniques in the Table are divided into 4 groups. Each part represents a group of techniques, either primary applying to a particular medium or mainly to improve production technology itself.

The first set of measures contains modern techniques, introduced within the last two decades in order to improve production technology, mainly with respect to productivity and cost efficiency. These techniques also include measures aiming towards a reduction in energy consumption within the steelmaking process, as a reduction in total or specific energy consumption usually implies a reduction in costs. Also modern concepts concerning the furnace technology itself are presented.

Sets two, three, and four represent techniques, that have been mainly implemented to comply with demands on environmental protection, but eventually also to use valuable outputs besides the steel. Set two deals with techniques concerning chiefly the protection of the medium air. Set three looks at different methods for the preparation or treatment of solid releases, that result from the steelmaking process (eg. slags, precipitated dusts, refractory breaks). Set four draws up possible measures for the handling of water flows possibly used or generated in the steelmaking process.

The construction of Table 4-1 shows available techniques in the rows, grouped the above mentioned way. In the columns are indicated qualitative environmental effects of each technique on the media, i.e. impacts on the amount of resulting emissions (eg. prevention), impacts on the consumption of energy and inputs, the effects on the collection performance for emissions into the different media, as well as the abatement potential for emissions for each medium (control). The columns "Collection of process emissions" and "Abatement of process emissions" are mainly related to the medium air, as for this medium primary measures to avoid the waste gas yield are not available and for this reason collection and abatement of the resulting emissions is the most important task. The consumption of input and energy is considered in two categories, "Consp. intern" and "Conspt. extern", to separate internal (within an EAF plant including secondary metallurgy) from external (eg. external dust treatment processes) effects. Furthermore, the effects of the techniques on the productivity and on the noise performance of electric steelmaking plants are indicated, too. The final three categories assign the techniques to the groups state of the art, retrofit measure, and emerging technique. The indicated effects on the different media are not complete, but selected with respect to important impacts. The use of Table 4-1 is explained by means of the example G5.

Generally, arrows down (↓) indicate savings of inputs or energy and a reduction of emissions into media. They also show effects of abatement measures with relieving tendencies for the environment. On the contrary, arrows up (↑) indicate an increase of emissions, consumption, etc. G5, the use of foaming slag practice, has several impacts on the production process. With respect to process emissions into the medium soil, it has two contrary effects. On the one hand, it saves refractory material by protecting the furnace lining from extreme heat radiation. This means a lower amount of refractory breaks possibly has to be land-filled or treated (soil ↓), it also means a saving of intern inputs (lining, conspt. intern ↓). On the other hand, foaming slag has a lower density than normal slag, so the volume of slag initially obtained increases (soil ↑), possibly leading to problems in plants using bucket, for the moment [50]. However, the tapped slag is also degassing again in the slag bed and partially reducing its volume. Furthermore, foaming slag practice decreases the required energy input by a better heat transfer (conspt. intern ↓). It increases productivity and can be considered as a retrofit measure as well as state of the art in modern (commercial steel) electric steelmaking.

Moreover, Table 4-2 depicts selected data for examples of electric steelmaking plants in Germany. It provides, in anticipation of the rest of this chapter, information on applied technologies within German electric steelmaking plants.

Table 4-1: Available Techniques for Integrated Pollution Prevention and Control (1)

Table 4-1: Available Techniques for Integrated Pollution Prevention and Control (2)

Table 4-2: Selected data for electric steelmaking plants in Germany (1)

Table 4-2: Selected data for electric steelmaking plants in Germany (2)

	PSAG, Peine	**GMH GmbH Georgsmarienhütte**	**Stahlwerke Thüringen GmbH, Unterwellenborn**
In operation since	1995	1994	1995
Furnace type	DC UHP furnace	DC UHP furnace	DC UHP furnace
Produced steel grades	carbon steel	carbon steel	carbon steel
Tapping weight [t]	100	125	120
Nominal apparent power of current transformer [MVA]	140	130	120
Raw materials	scrap	scrap	scrap
Cooling system	water cooled side walls and roofs	water cooled side walls and roofs	water cooled side walls and roofs
Tapping system	EBT	EBT	EBT
Capacity [t/a]	750,000	600,000	600,000
Additional burners	gas burners	oxygen gas burners	oxygen/natural gas burners (7)
Additional fuels	coal	coal	coal
Emission collection measures	2nd hole, hood	2nd hole, roof hood	2nd hole, ladle furnace dedusting, big furnace enclosure
Off gas cleaning system	post combustion chamber with additional burners quenching (air) fabric filter	post combustion chamber with additional burner quenching (water) fabric filter	post combustion fabric filter
Energy aspects	recovery of waste gas heat	recovery of waste gas heat	water cooled ducts
Secondary metallurgy	ladle furnace vacuum degassing	ladle furnace vacuum degassing	ladle furnace

4.3 General developments in modern production technology (including energy aspects)

4.3.1 Developments in general and resulting effects

Within the last decades significant improvements in EAF production technology have been introduced. Some of the most important measures implemented are [86, 49]:

- (Ultra) High power operation (UHP),
- Water cooled side walls and roofs,
- Oxy-fuel burners and oxygen lancing,
- Eccentric bottom tapping (EBT),
- Foaming slag practice,
- Ladle or secondary metallurgy,
- Automation.

Figure 4-1 depicts the furnace shell of a modern EAF in principle.

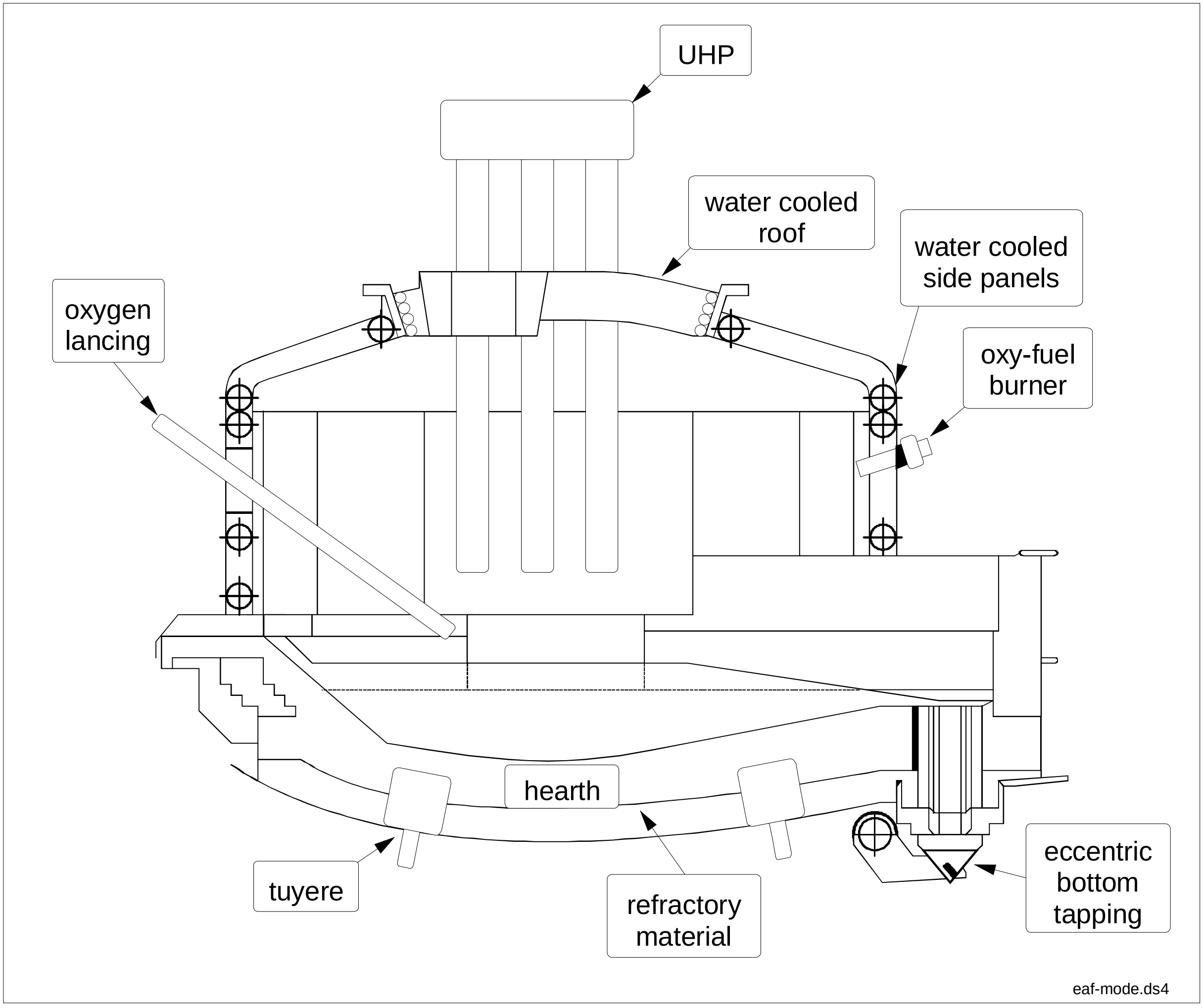


Figure 4-1: Electric arc furnace equipped with modern technology

Spots where some of the technologies apply to are indicated. Relevant features of the above mentioned measures are briefly discussed in the following.

Remark: Many of the modern German electric steel plants are equipped with the technologies or use operational practices mentioned in this section, for this reason no particular plants are stated as references. Some of the techniques may be retrofitted, but this has to be checked on a plant by plant basis. For the techniques mentioned in this section are mainly production rather than explicit environmental techniques, no particular provisions are laid down.

(Ultra) High power operation (G1):

The efforts to reduce tap-to-tap times led to the installation of more powerful furnace transformers. Decisive features for (Ultra) high power furnaces are installed specific apparent power supply, mean power efficiency (≥0.7), and timewise use of the transformer (≥0.7). UHP operation may result in a higher productivity, reduced specific electrode consumption, and reduced specific waste gas volume, but also in increased wear of the furnace lining [50].

Water cooled side walls and roofs (G2):

Within the last two decades, furnace walls and roofs have been lined with water panels, providing the opportunity to save refractory material, to use the (ultra) high power furnace technology, and also to re-use waste heat by the application of measures for energy recovery [6]. However, it has to be checked on a plant by plant basis, if the recovery of energy is economically viable.[5] In principle, two cooling systems can be distinguished. So-called cold or warm cooling draws off power losses by an increase of the cooling water temperature flowing through the pipe coils. Evaporation cooling works by the evaporation of cooling water to draw off radiation heat caused by the electric arcs. To protect water cooled side panels from thermal strain, especially when foaming slag operation (cf. below) is not possible, a computer controlled regulation of the melt-down process helps to prevent tears in the panels caused by mechanical tension and also saves refractory material [53]. An additional energy consumption by water cooled side walls and roof of about 10-20 kWh/t, that is stated in the literature, is assumed to be compensated by advantages in the field of plant availability and maintenance [48]. Water cooled side walls and roofs have inter alia provided the opportunity to apply modern technology like HP or UHP furnaces.

Oxy-fuel burners and oxygen lancing (G3):

Additional energy input into the furnace promotes a uniform melting of the scrap. It also partially offsets the effect of maximum demand control on electricity supply. Usually, additional energy input by oxy-fuel burners and oxygen lancing results in a decrease of total energy input required. On the other hand, it may increase the waste gas volume.

Eccentric bottom tapping (EBT, G4):

The practice of EBT is widely adopted nowadays, as it makes possible slag free tapping. It also allows cost savings for the lowering of refractory material needed, for a more rapid tapping, and for reduced energy losses. Furthermore, it simplifies the capturing of fumes. While some older furnaces still tap into runners, usually most of the new electric arc furnaces are equipped with EBT systems.

Foaming slag practice (G5):

Creating a foamy slag within the furnace improves the heat transfer to the charged inputs, and also protects the refractory material inside the furnace. Effects of the foaming slag practice are reductions in energy consumption, electrode consumption, noise level, and an increase in productivity. It also causes positive effects on several metallurgical reactions (eg. between slag and melt). The density of foaming slag is less than common FeO containing EAF slag (1.15-15 t/m^3 compared to 2.3 t/m^3). For this reason, the volume of slag arising during

[5] The same statement is true for energy recovery of waste gas cooling water (cf. 4.4.2, A7).

steelmaking is rising and may require the obtaining of new slag buckets [50]. After tapping, the slag partly degasses again. Information on adverse impacts of the foamy slag practice on the possibilities to use the slag have not been encountered. It has to be noted, that the use of foaming slag practice for high grade steelmaking is often not possible.

Ladle or secondary metallurgy (G6):
Some production steps need not be carried out in the EAF itself and can be performed more efficiently in other vessels (like desulphurising, alloying, temperature and chemistry homogenisation). These tasks have been shifted from the EAF to ladles, ladle furnaces, or other vessels nowadays [75, 25]. The reported benefits of this development are energy savings (net savings of 10-30 kWh/ton), a reduction of tap-to-tap times of about 5-20 minutes, increasing the productivity, a better control of temperature of the heat delivered to the caster, a possible reduction of electrode consumption (up to 0.1-0.74 kg/ton), alloy savings, and a decrease of the emissions from the EAF itself [16, 25]. A possible drawback of using ladles or other vessels with respect to air pollution control is the increase in the numbers of emission sources, requiring higher expenditure for air pollution control equipment, as additional fume capturing devices like hoods are needed.

Automation (G7):
Computer control in electric arc furnace plants has become necessary within recent years, as the high throughputs require efficient control systems to manage the material and data flows arising in the raw material selection, EAF, ladle furnace, and continuous caster. Efficient control systems permit an increase in productivity, a reduction in energy consumption, and also a decrease in dust emissions [55, 59].

Heat recovery of furnace cooling (G8):
As mentioned in G2, it is possible to recover the heat drawn away by the cooling system. This heat should be recovered, if possible, for steam production or district heating (cf. A7). However, this option has to be evaluated thoroughly with respect to economic viability.

Scrap sorting and cleaning (G9):
The provision of clean and pure scrap has been considered within the iron and steel industry to lower the formation of emissions, in particular dioxines [98]. Recent investigations showed that there seems to exist an impact of this measure on the raw gas composition, however, the influence on the clean gas side is significantly lower [43].

4.3.2 AC versus DC concepts

Furnaces can be distinguished fundamentally with respect to the type of electric current used (AC/DC). In recent years the Direct Current (DC) furnace technology has been enhanced significantly. Discussions and research activities are still ongoing to identify the advantages and disadvantages of DC furnaces compared to conventional Alternating Current (AC) furnaces. In recent publications tendencies have been observed, that investigations on the topic AC vs. DC furnaces are focusing on the performance differences between the two furnace types with respect to electrical efficiency, thermal efficiency, electrode consumption, flicker, simplicity and maintenance, magnetic fields, and related costs [12, 13, 54]. So far, there seem to be both advantages and disadvantages for either technology, which roughly compensate each other. However, it is an interesting fact, that three recently built electric arc furnaces in Germany are DC furnaces [102], whereas all other German furnaces employ the AC furnace technology. For the still ongoing discussions about advantages and drawbacks of either of the technologies, neither one is proposed explicitly as a candidate BAT. The stated data ranges are valid for both of the technologies. AC and DC furnace technology can be considered as an interchangeable basis for secondary steelmaking at this moment. Though the technologies may differ with respect to certain details, these will not be considered in this technical note, as they are negligible in the context of this paper.

German plants equipped with DC technology (examples):
Georgsmarienhütte GmbH, Georgsmarienhütte, 125 t, 130 MVA,
Preussag Stahl AG, Peine, 100 t, 140 MVA,
Stahlwerke Thüringen GmbH, Unterwellenborn, 120 t, 145 MVA.

German plants equipped with AC technology (examples):
Badische Stahlwerke, 2 furnaces, 85 t, 68 MVA, 85 t, 68 MVA,
Benteler AG, Lingen, 85 t, 85 MVA,
BES GmbH (Riva), Brandenburg, 2 furnaces, 150 t, 102 MVA, 150 t, 76 MVA,
Edelstahlwerke Buderus, 100 t, 57 MVA,
EWK Edelstahl GmbH, Witten, 110 t, 75 MVA,
HES GmbH (Riva), Henningsdorf, 2 furnaces, 70 t, 86 MVA, 70 t, 86 MVA,
ISPAT Hamburger Stahlwerke, 115 t, 105 MVA,
Krupp Edelstahlprofile, 140 t, 75 MVA,
Krupp Thyssen Nirosta, Bochum, 145 t, 135 MVA,
Krupp Thyssen Nirosta, Krefeld, 80 t, 85 MVA,
Lech Stahlwerke, Herbertshofen, 2 furnaces, 70 t, 40 MVA, 70 t, 40 MVA,
Mannesmannrohr GmbH, Bous/Saar, 70 t, 45 MVA,
Saarstahl AG, Völklingen, 125 t, 55 MVA,
Stahlwerk Oberhausen, Oberhausen, 135 t, 96 MVA.

4.4 Techniques concerning the medium air

Protection of the medium air related to EAF steelmaking primarily takes place by employing end-of-pipe measures, as dust generation is an inherent feature within the electric steelmaking process. The basic scheme to prevent air pollution caused by electric steel plants is to collect the releases into the air (generally off gases loaded with particulates) and to precipitate particulates in order to minimize the dust content of the gas flow released into atmosphere. In general, a post combustion of waste gases is necessary to alter the chemical composition of the gas in order to prevent further danger (i.e. burning CO into CO_2, possibly cracking dioxins generated during the melting phase).

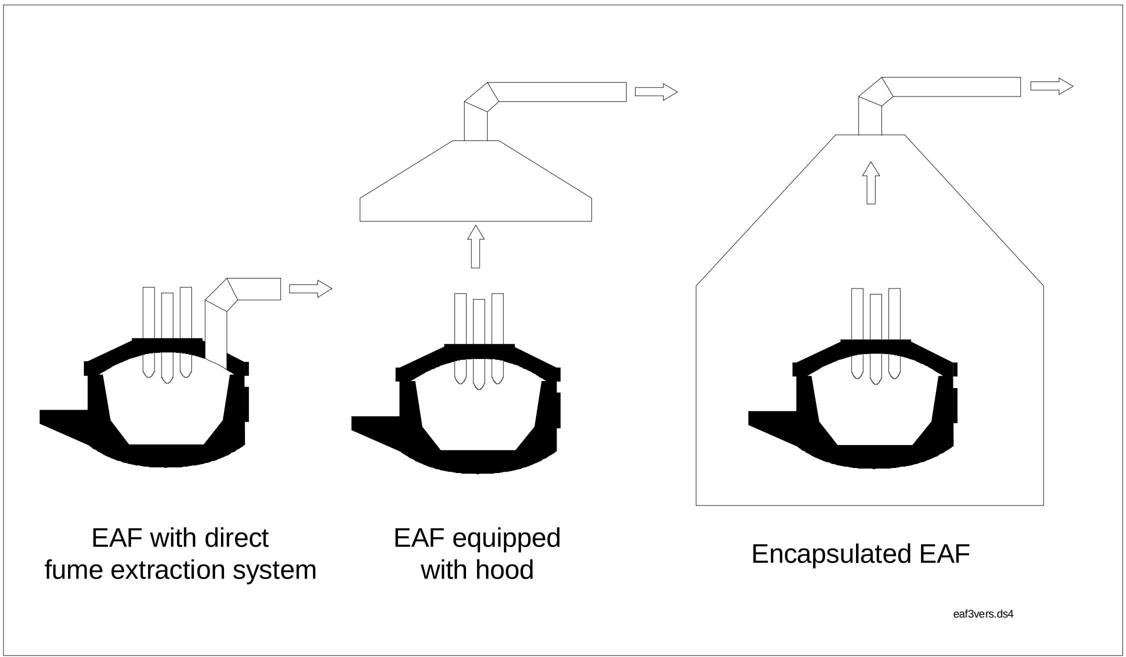
4.4.1 Collection of emissions into the air

Principally, emissions of electric steelmaking plants include waste gases (CO, CO_2, NO_x, VOC, etc., cf. Table 3-3) and particulates, that are composed of various metal and non-metal compounds. NO_x is emitted from the furnace during the melting operation.[6] Emissions of VOC arise if the scrap used as raw material contains corresponding substances.

Available techniques for the collection of waste gases generated in EAF plants are:

- Direct extraction of (primary) process fumes via a complementary furnace opening (DC: "2^{nd}", or AC: "4^{th}" hole),
- Canopy or hood system above the furnace,
- The encapsulation of the furnace and eventually preceding and succeeding installations in a building (dog-house or total building evacuation[7]).

The principal working scheme for each of the technologies is depicted in Figure 4-2.



6 Further details on heavy metal, NO_x, and SO_2 emissions from secondary steelmaking plants into the atmosphere and emission control measures inter alia can be found in [78].

7 The limits between a tight furnace encapsulation, a more spacious furnace encapsulation, and a total building evacuation are somewhat fuzzy. The use of the term ‘dog-house’ for a tight furnace encapsulation is quite common, but it may also denote more spacious encapsulations up to a total building evacuation. On the other hand, VAI offers more spacious furnace encapsulations for EAF and refers to this construction as ‘elephant house’ [96].

Figure 4-2: Options for collecting EAF dusts

Direct extraction of process fumes (A1):
A 4th, or 2nd hole collects some 95% of the primary emissions generated during the melting and refining periods [16]. This type of direct extraction technology is state of the art in modern EAF steelmaking for the collection of primary emissions. It can also be applied to secondary metallurgy vessels.

German plants equipped with direct fume extracting device (examples) [93]:
All major German electric steelmaking plants are equipped with 4th or 2nd holes.

Hood system (A2):
In a hood system, one or more hoods over the furnace indirectly collect fumes escaping from the furnace during the charging, melting, slag-off, and tapping steps (up to 90% of primary emissions and also secondary emissions [16]). Hood systems are commonly used within the secondary steel industry in addition to direct extraction systems, improving the collection share to 98% of primary emissions and also secondary emissions. Hoods are also installed to collect emissions arising at secondary metallurgy vessels, hoppers and conveyor belts.

German plants equipped with hood systems (examples) [93]:
All major German electric steelmaking plants use hoods for secondary dedusting.

Furnace enclosure (A3):
Furnace enclosures, also called dog-houses, usually encapsulate the furnace, its swinging roof, and also leave some working space in front of the furnace door. Typically, waste gases are extracted near the top of one of the walls of the enclosure, and makeup air enters through openings in the operating floor [25]. More complex handling steps, causing time losses and possibly higher investments (eg. need for additional door opening and closing mechanisms and procedures in order to charge and empty the furnace) are drawbacks of this type of collection technology. Collection rates of dog-houses are similar or usually slightly higher to those of hood-complementary hole combinations. A positive effect of furnace enclosures is a reduction in the noise level, if they are constructed in a suitable manner [70]. Noise abatement at an EAF plant by sound protecting enclosures can reduce the average sound pressure level between 10 and 20 dB(A) [58].[8] Furnace enclosures may also be applied at secondary metallurgy processes [16].

German plants equipped with furnace enclosures (examples) [93]:

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8 Information provided by industry.

Benteler AG, Lingen, 85 t, 85 MVA,
Krupp Thyssen Nirosta , Bochum, 145 t, 135 MVA,
Krupp Thyssen Nirosta , Krefeld, 80 t, 85 MVA,
Mannesmannrohr GmbH, Bous/Saar, 70 t, 45 MVA,
Moselstahlwerk, Trier, 48 t, 30 MVA,
Stahlwerke Thüringen GmbH, Unterwellenborn, 120 t, 145 MVA.

Total building evacuation (A4):

Another way to collect emissions from the furnace, as well as preceding and succeeding installations, is a complete enclosure of all plants in one sealed building[9]. The erection of such buildings and the additionally required large dedusting installations in order to achieve complete dedusting impose considerable costs on the operators. For this reason, the costs and benefits need to be weighed up carefully for every special plant before this option is considered. A positive effect of this measure is a reduction in the noise level penetrating to the outside. Usually, the pressure in the enclosing building is below atmospheric pressure to avoid the escaping of fumes through occasional door openings.

German plants equipped with a total building evacuation (examples):
No information available, at the moment.

As already mentioned above, combinations of the technologies shown are possible and common. In particular, the combination of direct fume extraction and a hood system is often used. This combination achieves a collection of about 98% of the primary emissions. In addition, a significant share of charging and tapping (secondary) emissions can be collected, too, though this depends on the type and the number of hoods [16]. A combination of a direct extraction device and a furnace enclosure even achieves collection rates of over 97% up to 100% of the total dust emissions [43, 70].

4.4.2 Handling of waste gases

The handling of collected waste gases is an important task in order to render them harmless and to possibly use their energy content [59]. Generally, three main purposes of waste gas handling can be identified:

- Minimization of the pollution potential of the waste gases,
- Cooling down of the waste gases to the required entrance temperature of the precipitator,
- Use of the waste gas energy content.

Post combustion of waste gases (A5):

---

9 A total building evacuation can be regarded, roughly speaking, as just a larger type of furnace enclosure, mainly containing more process steps.

The pollution potential of the waste gas has to be minimized to prevent negative impacts on the environment, inter alia by CO, VOCs, or dioxins. This task can partly be achieved by the post combustion of waste gases. CO is oxidised into CO_2, as well as C_nH_m to CO_2 and H_2O, also dioxins generated during the melting period may be cracked this way. Post combustion of waste gases can be performed by additional burners as well as by the supply of secondary air [97], both in the duct or in a combustion chamber, or also in the furnace itself. Using an extra post combustion chamber, possibly equipped with additional burners, may help to improve the oxidation of CO, C_nH_m, and dioxins [90], for it helps to control the staying time and temperature of the waste gas by the geometry of and the energy input into the chamber. Post combustion in the furnace allows a partly utilization of the chemical energy of the carbon monoxide contained in the waste gas. For this practice, burners or lances are used to add oxygen in an excess stoichoimetric relation. However, the extensive use of oxygen bears the danger of an oxidation of iron. An evaluation of this practice has therefore to take into account several factors like energy use, yield, tap-to-tap time, etc. [43].

German plants equipped with an extra post combustion chamber (examples) [90, 97]:
Badische Stahlwerke, 2 furnaces, 85 t, 68 MVA, 85 t, 68 MVA.

German plants applying other post combustion techniques (examples):
Krupp Thyssen Nirosta, Bochum, 145 t, 135 MVA,
Stahlwerk Oberhausen, Oberhausen, 135 t, 96 MVA.

Cooling of waste gases (A6):

The waste gas has to be cooled down to the required entrance temperature of the precipitation system. This can be done in a way that prevents the formation of hazardous substances. Depending on the precipitation system in use, the waste gases have to be cooled down from 1,400-1,700 °C (reaction chamber) to 130-300 °C (entrance electrostatic precipitator, bag filter). Options for a controlled cooling down of the gases are:

- A mixing of the hot primary waste gases with the cooler gases of the secondary dedusting system (air quenching),
- A conduction of primary waste gases through water cooled ducts,
- A spray cooling of gases with water (water quenching), and
- combinations of these measures.

Rapid cooling of waste gases (quenching, wet with water or dry with air) is considered to prevent a de novo synthesis of dioxins [98].

German plants equipped with quenches (examples):
Badische Stahlwerke, 2 furnaces, 85 t, 68 MVA, 85 t, 68 MVA,
Preussag Stahl AG, Peine, 100 t, 140 MVA.

Use of energy content of waste gas (A7):

The third purpose of waste gas handling is to use the waste gas energy content of up to 150 kWh/t, of which more than 80 kWh/t can be chemical energy [28]. This task is often related to environmental problems, as scrap preheating, that would be a suitable option for the recovery of energy from the waste gas, presents problems with respect to the formation of dioxins [47]. New furnace concepts with shaft integrated scrap preheating try to manage the related dioxin problems to scrap preheating by applying closed systems (cf. 6.1). As in the case of recovering the heat from the EAF cooling water, it has to be evaluated on a plant by plant basis, if a the use of the energy content of the waste gas is economically viable. Recovered energy (heat) of an EAF plant may be used for steam production or district heating (cf. G8).

German plants equipped with cooling systems allowing energy recovery (examples):
Krupp Thyssen Nirosta, Bochum, 145 t, 135 MVA.

The mentioned purposes of waste gas handling are partly contradictory. For example, the speed of cooling down the waste gas also has an influence on the extent to which dioxins are formed[10]. It is sometimes difficult to strive for both goals successfully, as a rapid cooling may

10 According to a recent investigation, rapid cooling (quenching) of waste gases prevents the de novo synthesis of dioxins [97].

prevent the use of the energy content of the waste gas. A general approach to prevent the formation of dioxins in electric arc furnaces has been considered to be the provision of clean scrap [98], but recent investigations showed that this has only an impact on the raw gas. If a suitable gas cleaning system is in use, scrap sorting will not effect significantly the clean gas composition with respect to dioxines.

4.4.3 Precipitation of particulates

The precipitation of particulates carried along by the waste gas flow is a decisive step to abate air pollution. In the main, three ways exist to precipitate the particulate load of waste gas[11]:

- gas cleaning by wet scrubbing,
- gas cleaning using electrostatic precipitators,
- gas cleaning using bag filters.

As at 1997, all major electric steelmaking plants in Germany are equipped with dry dedusting systems. Among the 25 biggest secondary steelmaking plants, that represent over 97% of the production capacity for electric steel in Germany, 80% have gas cleaning systems using fabric filters [7, 93]. The other steelmaking plants are also equipped with dry dedusting systems, usually dry electrostatic precipitators. Depending on the efficiency of the precipitators, up to 99,5% of the particulate load can be precipitated, leaving 1-20 mg/m^3(STP) dust in the flue gas leaving the system limits. The collected dust amounts to specific mass flows of about 10-20 kg/t, depending on the type of steel produced.

Wet scrubber:

Wet precipitation systems are no longer in use in major German electric steel plants mainly due to the problems with arising sludge and waste water treatment.

German plants equipped with wet scrubber [93]:

E.+ St. W. Pleissner, Herzberg/Harz, 3 furnaces, 5 t, 2.5 MVA, 8 t, 3.5 MVA, 5 t, 2.5 MVA.

Electrostatic precipitator (A8):

In principle, electrostatic precipitators remove solid or liquid particles from a gaseous medium by charging the particles with an electrical load and precipitating them onto a receiving surface in an electric field. Next to bag filters, electrostatic precipitators are the only type of gas cleaning systems used in major German electric steel plants. Dry electrostatic precipitators, that are installed at German electric steel plants, achieve clean gas dust concentrations below 20 mg/m^3 (STP).

[11] For a more detailed description of the precipitation systems mentioned cf. [78].

German plants equipped with electrostatic precipitators (examples) [93]:

EWK Edelstahl GmbH, Witten, 110 t, 75 MVA,

Krupp Thyssen Nirosta, Bochum, 145 t, 135 MVA,

Krupp Thyssen Nirosta, Krefeld, 80 t, 85 MVA,

Stahlwerk Oberhausen, Oberhausen, 135 t, 96 MVA,

Thyssen Guss AG, Mülheim (Ruhr), 7 t, 4.2 MVA.

Bag filter (A9):

As mentioned, modern German EAF steelmaking plants are equipped with bag-houses containing fabric filters. Fabric filters separate dust particles from a gas stream by retaining and collecting the particles on the surface and in the interior of the filter material. Clean gas dust concentrations from 20 mg/m^3 (STP) to usually below 5 mg/m^3 (STP) can be achieved by the use of fabric filters. The good cleaning performance of a bag filter makes it a suitable option for gas cleaning in EAF plants. However, from the power consumption point of view, electrostatic precipitators seem to consume half the power for the same volume of waste gas, whilst also achieving clean gas dust concentrations below 20 mg/m^3 (STP) [49]. On the other hand, bag filters are considered to have superior separating effects with respect to PCDD and PCDF emissions [87]. Examples for the dust cleaning performance of bag filters show dust concentrations between 0.625 mg/m^3 (STP, hourly mean value outlet steel division) [20] and 1.4 mg/m^3 (STP, yearly mean value) [90].

German plants equipped with bag filters (examples) [93]:

Badische Stahlwerke, 2 furnaces, 85 t, 68 MVA, 85 t, 68 MVA,

Benteler AG, Lingen, 85 t, 85 MVA,

BES GmbH (Riva), Brandenburg, 2 furnaces, 150 t, 102 MVA, 150 t, 76 MVA,

Edelstahlwerke Buderus, 100 t, 57 MVA,

Georgsmarienhütte GmbH, Georgsmarienhütte, 125 t, 130 MVA,

HES GmbH (Riva), Henningsdorf, 2 furnaces, 70 t, 86 MVA, 70 t, 86 MVA,

ISPAT Hamburger Stahlwerke, 115 t, 105 MVA,

Krupp Edelstahlprofile, 140 t, 75 MVA,

Lech Stahlwerke, Herbertshofen, 2 furnaces, 70 t, 40 MVA, 70 t, 40 MVA,

Preussag Stahl AG, Peine, 100 t, 140 MVA,

Saarstahl AG, Völklingen, 125 t, 55 MVA,

Stahlwerke Thüringen GmbH, Unterwellenborn, 120 t, 145 MVA.

4.4.4 Reference data for gas cleaning systems of German electric steelmaking plants

This section presents data of four German electric steelmaking plants, equipped with different waste gas cleaning systems. All the plants meet the German standards for air pollution control laid down in the TA Luft (Technische Anleitung Luft). Table 4-3 provides a description of the features of the gas cleaning systems and achieved clean gas concentrations of dust as well as an analysis of the average compositions of the waste gases.

Table 4-3: Gas cleaning systems and performance of German EAF plants

Plant	**EAF 1**		**EAF 2**			**EAF 3**		**EAF 4**			
Features:											
Tapping weight [t]	105		138			85/85		140			
Power supply [MVA]	105		96			57/68		105			
Collection of emissions	4th hole hood		4th hole hood			4th hole hood		4th hole furnace encapsulation			
Post combustion (PC)	PC chamber (air)		PC in duct			PC chamber (air)		PC in duct			
Waste gas cooling	Injection of water		Water conditioning of waste gas			Spray cooling system (quenching)		Cooling by air cooled heat exchanger			
Off gas cleaning system	Bag filter		Electrostatic precipitator			Bag filter (1 for both)		Two bag filters for primary and secondary dedusting			
Gas concentrations: *	**M 1 ****	**M 2**	**M 1**	**M 2**	**M 3**	**M 1**	**M 2**	**M 1**	**M 2**	**M 3**	**M 4**
Dust in crude gas (p)	3,398	14,246	4,200	12,500	3,600	-	-	-	-	-	
Dust in crude gas (s)	148	273	p and s together			-	-	-	-	-	-
Dust in clean gas (p)	0.76	1.05	15	15	18	1.45	1.1	<1	<1	<1	<1
Dust in clean gas (s)	average °		-	-	-	average °		<1	7	3	<1
Dioxin (I-TE, p)	-	-	-	-	-	-	-	0.252	0.201	0.240	0.810
Dioxin (I-TE, s)	-	-	-	-	-	-	-	0.027	0.010	0.023	0.057
Dioxin (Mix, p and s)	0.016	0.021	0.01	0.02	0.01	0.13	0.1	0.087	0.061	0.081	0.259

*: Crude and clean gas dust concentrations in mg/m^3 (STP), Dioxin concentration in ng/m^3 (STP, clean gas)

**: M #: Number of measurement at the plant

(p): Concentrations at primary dedusting device

(s): Concentrations at secondary dedusting device

°: Average of two measurement spots, -: no information available

Source: [87]

Table 4-4 shows an analysis of mean clean gas concentrations of relevant heavy metal contents of the four electric steelmaking plants investigated.

Table 4-4: Analysis of mean heavy metal concentrations in the clean gas

Element	**Cadmium**	**Nickel**	**Chromium**	**Manganese**	**Tin**
µg/m^3 (STP)	2	18	49	125	17
Element	**Mercury**	**Lead**	**Copper**	**Vanadium**	
µg/m^3 (STP)	46	56	10	8	

Source: [87]

Possibilities and requirements to treat the resulting (now) solid dusts are discussed in the following section 4.5.2.

4.4.5 Further aspects

Emissions into the air arising at raw materials storage, handling and preparation are possible releases of EAF plants. Operations for handling fluxes should be kept to a minimum and where appropriate dust extraction equipment should be used. Powdered carbon and lime can be stored in sealed silos and conveyed pneumatically or stored and transferred in sealed bags to minimise emissions. Lime should be kept dry. [46]

The Swedish EPA commented with respect to NO_x formation in electric steelmaking plants, that the use of a slight overpressure (0.2 mm H_2O) in the EAF is believed to reduce the formation of nitrogen oxides for the prevention of entering excess air into the EAF. The introduction of this operational practise reduced the specific NO_x emissions (kg NO_x/tonne steel) in a Swedish electric steelmaking plant from 0.081 to 0.034 kg NO_x/tonne steel [85].

4.5 Techniques concerning the medium soil

In the main, there are three types of solid releases to be considered with respect to integrated pollution prevention and control, that result from the electric steelmaking process next to the desired product steel. In detail, the following solids are produced during the processes and have to be controlled:

- slags,
- precipitated dusts, and
- refractory breaks.

The yield and exact composition of these materials generally depend on operational practices and the type of steel produced, as the adjustment of the chemical composition of the steel determines the characteristics of the solids.

4.5.1 Treatment of slags

Like dust-generation, slag-forming is an indispensable part of the steelmaking process and can not be prevented or controlled totally. Slags usually arise at two places within an electric steelmaking plant. In the EAF itself an oxidising slag is formed, furthermore a refining slag is obtained in the secondary metallurgy process. General statements about the yield and composition can mainly be made for EAF slag, as its features are mostly similar within different plants. The yield and composition of secondary metallurgy slags are dependent on the desired output. Significant differences exist between the amount and composition of secondary metallurgy slags obtained by the production of commercial steels and high-grade steels.

4.5.1.1 Handling of EAF slags

In an EAF the slag amounts to about 100-150 kg per ton of steel produced [75, 98]. EAF slag can be regarded as an artificial rock, similar to natural rock [29], consisting of iron-oxides (FeO), lime (CaO), silicium-oxide (SiO_2), and other oxides (MgO, Al_2O_3, MnO). Examples for typical slag compositions of German EAF plants have already been provided in Table 3-2.

EAF slags are characterised by high strength, good weathering resistance, and also high resistance against polishing. They also have properties, that make them suitable for use in hydraulic engineering [43]. An important criterion for the use of EAF slag in general is the constancy of volume, which has to be checked for the specific application.

Use in road construction (S1):

Commonly, EAF slags are used in the field of construction after a preparation treatment for the mentioned features. Depending on the actual composition, the slags can be used for road construction, earth fill, or hydraulic engineering. The deciding factors with respect to these uses are environmental acceptability and structural suitability. If the required legal conditions for use in construction are met [cf. 29], the EAF slag has to be crushed, screened, and sized for use. Ferrous slag components are separated via magnetic precipitators, if possible. The treated slag is used in various construction purposes, also dependent on the grain size. Figure 4-3 shows a processing scheme for a German plant for slag preparation [22]. In 1994, about 90% of EAF slags generated by the production of non- and medium-alloyed steel have been used [43]. Slags arising at high grade steel production are only used to a limited extent, so far. Possible uses may be also in the road construction area, after a preparing treatment.

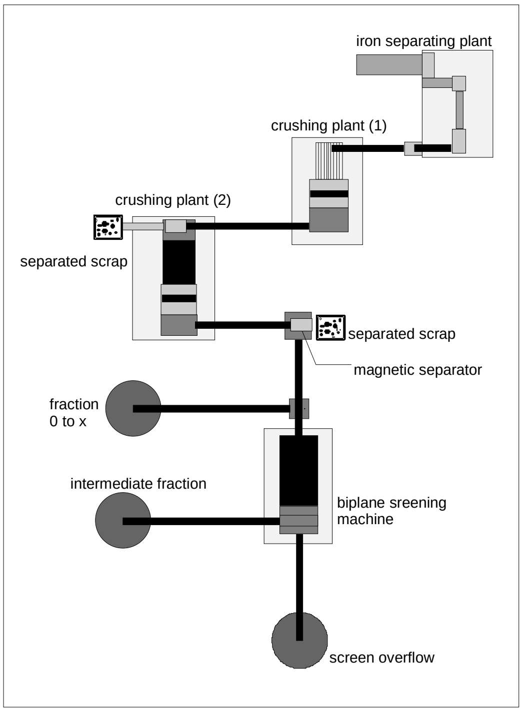

Figure 4-3: Processing scheme of a plant for slag preparation

EAF slag re-use strategies of German plants (examples):

Badische Stahlwerke, 2 furnaces, 85 t, 68 MVA, 85 t, 68 MVA: Treatment and use in the construction area.

Georgsmarienhütte GmbH, Georgsmarienhütte, 125 t, 130 MVA: Selling for external preparation. Use in the road construction area.

Preussag Stahl AG, Peine, 100 t, 140 MVA: Treatment and use in the construction area.

4.5.1.2 Handling of secondary metallurgy slags

Options to use the wide spectrum of secondary metallurgy slags are limited. Grain size and constancy of volume are decisive factors for the use of secondary metallurgy slags. They sometimes may be used in the construction area. But a significant share of the arising slags has to be landfilled, as hardly an option for prevention, reduction, or utilisation exists [50].

Secondary metallurgy slag re-use strategies of German plants (examples):

Georgsmarienhütte GmbH, Georgsmarienhütte, 125 t, 130 MVA: EAF and secondary metallurgy slag are used together (cf. 4.5.1.1).

Processing to lime-fertiliser or recycling into EAF (S2):

Some secondary metallurgy slags can be employed as lime-fertiliser after treatment. Others may be crushed and recycled with the addition of lime into the EAF. However, these uses depend greatly on the composition of the slags, on desired product qualities (a recycling of crushed slag is not possible for high grade steels), and on market restrictions (usually, other ways to produce lime-fertiliser are cheaper [34]).

German plants recycling secondary metallurgy slag or processes it to lime-fertiliser (examples):

No information available at this time.

4.5.2 Treatment of precipitated dusts

Depending on the type of steel produced, about 10-20 kg/t steel of dust are precipitated by the gas cleaning facilities, permitting less than 0,2 kg/t steel of dust to enter into the atmosphere. This figure depends on the collection efficiency of the precipitator in use.

Precipitated dusts obtained by the gas cleaning facilities usually contain a significant share of heavy metals. These are toxic and might be leachable, necessitating special care for further processing and possibly the landfill of the dusts. Examples for compositions of EAF dust from different German and further plants, also distinguished by commercial and high grade steel grades, are given in the Annex (cf. 8.2). Dust composition usually varies from plant to plant, inter alia depending on the type of scrap used, which itself varies with respect to its origin.

4.5.2.1 Options to treat electric arc furnace dust in principle

Generally, there are several ways of handling EAF dust, which can be classified roughly into three categories [51]:

- Chemical stabilisation or vitrification,
- Recycling of dusts by returning them to the EAF,

- Hydrometallurgical and pyrometallurgical processes for zinc recovery and removal of heavy metals.

These options are desirable to different degrees according to their potential to satisfy the aim of prevention and control of environmental pollution. The use of the iron and heavy metal content of the dust is usually preferable to landfilling.

Chemical stabilisation and vitrification:
Chemical stabilisation and vitrification are both stabilisation processes at low, or high temperatures, usually in order to prepare EAF dusts for landfilling. Solidification (eg. pelletising) is also a possible pretreatment step for the recycling of dusts into the EAF. Stabilisation processes rely on the principles of encapsulation, ion exchange, precipitation and polymerisation. The fine EAF dust particles are incorporated into an aluminosilicate network to reduce the surface area and to immobilise the heavy metal ions. To ensure a proper functioning of the process, i.e. to ensure effective immobilisation of the heavy metals, a careful process control is necessary. As a deposition of precipitated EAF dust should be prevented if other reasonable options exist, solidification and vitrification cannot be considered to be a candidate BAT, at this moment.

Recycling of precipitated dusts (S3):
Recycling of precipitated EAF dusts by returning them to the EAF results in certain impacts on the steelmaking process. On the one hand, recycling decreases the volumetric disposal rate of the dust and increases its zinc content (up to 30-40%[12]) and also the iron content of the dust is returned in EAF process. On the other hand dust recycling possibly reduces furnace efficiency and rises the consumption of electrical energy (appr. 20-30 kWh/t) [56]. Technically, the returning of dusts is limited to a certain share of the total dust yield, depending on each steelmaking facility. Also the method of dust addition to the furnace affects the performance of the furnace. To improve performance, some form of pretreatment to agglomerate the dust, like pelletising or briquetting, is usually beneficial, as it reduces the share of dust that is just blown through the furnace. According to figures in the literature, the zinc content of the dust and the dust loading increase at the filter can vary, depending on the blow through rate, between 27-32% and 40-21% [51]. For example, a German electric steelmaking plant recycles 75% EAF dust of an original yield of 20-22 kg/t and has finally to take care of about 50% of the dust with an average zinc content of 35%. Generally, the dust is added at the beginning of each melting phase. In principle, the feasibility of EAF dust recycling depends on many factors, that may be dissimilar for different plants.

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[12] Information provided by industry.

German plants recycling EAF dust (examples):

Georgsmarienhütte GmbH, Georgsmarienhütte, 125 t, 130 MVA.

Zinc recovery and removal of heavy metals:

Processes for zinc recovery and removal of heavy metals are suitable options for reclaiming valuable resources, that have already been mined and treated, at least once. Pyrometallurgical and hydrometallurgical options exist for the recovery of zinc, in principle. Important parameters of these processes are temperature, heat source (if any), oxygen potential, consumables (energy, flux, etc.), pH-value or basicity, end product forms and uses, and disposal options for off gas and residues. Zinc recovered by the different technologies can be in the form of metal or oxide. An economic viable recovery of the zinc content of EAF dust requires a minimum percentage of zinc available in the dust. Commercially viable hydrometallurgical technologies are not available at this time [51].

The objective of the (pyrometallurgical) high temperature recovery processes is to reduce and fume away the heavy metals (i.a. zinc and lead), leaving an oxide and/or metallic residue substantially free of heavy metals. First of all the dust is optionally mixed with a reductant and fluxes, then it is heated in a fuming reactor. The zinc contained in the flue gas is then collected as condensed metal or oxide. It can be used to produce a wide range of products. Further residues of pyrometallurgical processes may also be utilised, depending on the process. In the following some pyrometallurgical technologies used in Germany are presented as candidate best available technologies. It is a common feature of all the presented pyrometallurgical processes, that their products substitute for other inputs, but they also require a certain energy input, causing costs. However, the treatment of precipitated dust seems to be a suitable option to avoid dust landfilling and to save resources.

4.5.2.2 Treatment of EAF dust (commercial steel production)

Waelz-process (S4):

Among the high temperature zinc recovery processes, the Waelz-technology (treatment in a rotary kiln) is the most common in Germany, at the moment. This process, used for the treatment of EAF carbon steel dust in Germany, recovers zinc in the form of an oxide. The required percentage of zinc in EAF dust, so that the Waelz-process is economically viable, is at least 17-18%.[13] The desired product of the Waelz-treatment is an oxide, called „waelz oxide“, with a share of about 56-60% zinc and 7-10% lead. Figure 4-4 shows a schematic overview of a Waelz-plant and Table 4-5 a specific input/output balance of this process [79].

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[13] Information provided by industry.

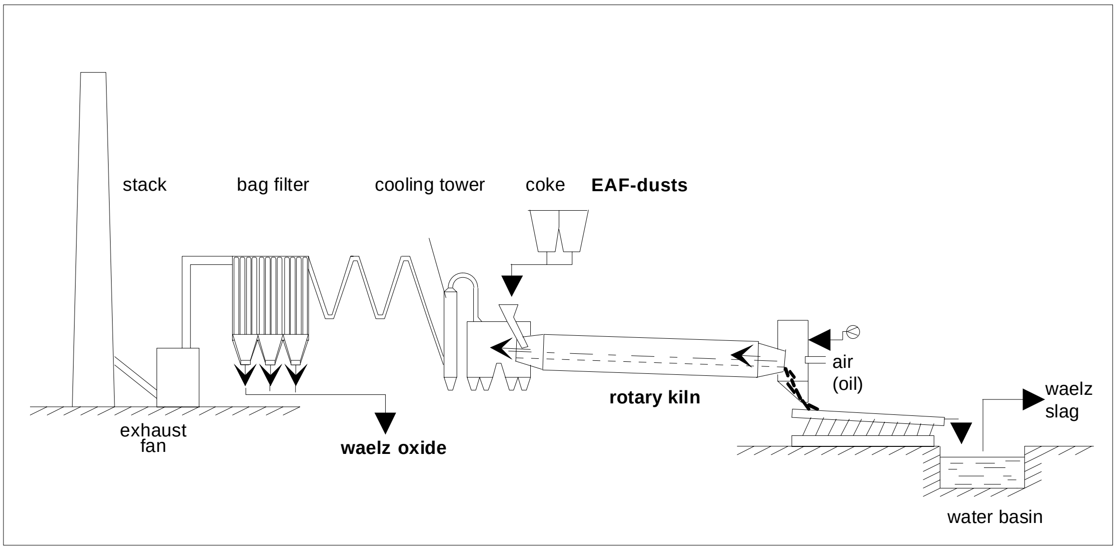

Figure 4-4: Schematic view of a Waelz-plant

The oxide produced then serves again as a resource in the non-ferrous metal industry. In Germany, there exist three plants to treat EAF dusts, that employ the Waelz-technology. Two plants, located in Duisburg and Freiberg, are run by the B.U.S. AG, the other plant is operated by Harz-Metall GmbH and located in Oker.

Table 4-5: Specific input/output balance of the Waelz-process

Inputs			**Outputs**		
EAF dust	kg/t	1000	**Waelz oxide**	kg/t	400
Coke breeze	kg/t	340-380	**Slag**	kg/t	700
Sand	kg/t	150-200	**Waste gas**		n.a.
Air	m^3/t	2,200			
Energy	GJ/t	11.1			
Of that**:** **Electrical energy**	kWh/t	87			
Oil		n.a.			

German plants using the Waelz-process (B.U.S. AG) to treat EAF dust (examples):

Badische Stahlwerke, 2 furnaces, 85 t, 68 MVA, 85 t, 68 MVA,

Preussag Stahl AG, Peine, 100 t, 140 MVA.

DK-process for commercial steel dust (S5):

DK Roheisen und Recycling GmbH operates two blast furnaces located in Duisburg producing cast iron from iron containing residues. Among other inputs like mill scale, oily mill scale, BF-dusts, BF-sludges and steelworks dust, EAF-dusts are processed, too.[14] The raw materials are agglomerated in a sinter plant. Each year 250,000 t of pig iron are produced from an 450,000 t input of residues. Other products that can be recovered by this process are lead,

[14] Information provided by industry

zinc-containing scrubbing sludge (about 60% Zn), and BF-slag. These outputs can be sold to non-ferrous metal producers or be used in the construction area.

Imperial Smelting Furnace (S6):

The Imperial Smelting Furnace (IS-furnace) is a shaft furnace, that uses the pyrometallurgical principle to produce non-ferrous metals. Input of the IS-furnace is inter alia sintered or briquetted Waelz-oxide, resulting from the treatment of EAF-dusts. The Mount Isa Mining (M.I.M.) Hüttenwerke Duisburg GmbH is running an IS-furnace in Duisburg. Recently, M.I.M. has put into use a technology, that makes it possible to inject directly EAF-dust into the furnace, without the need to treat the dust by the Waelz-process and hot briquetting. By this process 10,000 tons per year EAF dust are used, at the moment. M.I.M. plans to expand this use by 40,000 t/a within one year [83].

Recently, a considerable number of new pyrometallurgical processes for the recovery of heavy metals contained in EAF dusts have been developed [30, 68, 74]. Some of these new processes have been or will be realised on an industrial scale. Among these processes is the BSW-treatment [23], of which a schematic view is provided in chapter 6.3.[15] As this process can not be considered state of the art in Germany, at the moment, it is dealt with later with in the chapter "emerging techniques".

4.5.2.3 Treatment of EAF dust (high grade steel production)

Treatment of high grade steel dust by a special type of EAF (S7):

For the treatment of dusts from high grade (stainless) steel EAF production no plant is currently in operation in Germany. For this reason, a considerable share of the German high grade steel dusts are treated by B.U.S. AG in northern France. The dusts are prepared by means of a pyrometallurgical process with a special type of submerged arc furnace [26]. This process aims to recover valuable alloy metals like chromium, nickel, and molybdenum.[16] It has the following course: After delivery of the residues at the plant and initial handling, organic or inorganic binders added in a downstream briquetting stage, then the residues are fed into a roller press. The briquettes are charged into a dosing tower, where they are mixed with fluxes and reductants. The resulting furnace charge is loaded into the furnace, melted and tapped. The tap-to-tap time is about 2.5 hours. Releases of the furnace are a metal-slag mix and off gas. The off gas is cleaned with a bag filter. Resulting dusts are processed further with the rotary kiln process. The metal-slag mix is crushed, separated and used according to its characteristics. Recovered valuable metals vary in accordance with the steel works

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[15] In autumn 1997, BSW is going to start the construction of a plant for treating EAF dust with a final capacity of 25,000 t/a. The investment will be about 20 million DM [71].

[16] Information provided by industry.

productions programs delivering the dusts [26]. Figure 4-5 provides a processing scheme of this process.

German plants using the special type EAF to treat high grade steel dust (examples)[17]*:*

Krupp Thyssen Nirosta, Bochum, 145 t, 135 MVA,

Krupp Thyssen Nirosta, Krefeld, 80 t, 85 MVA.

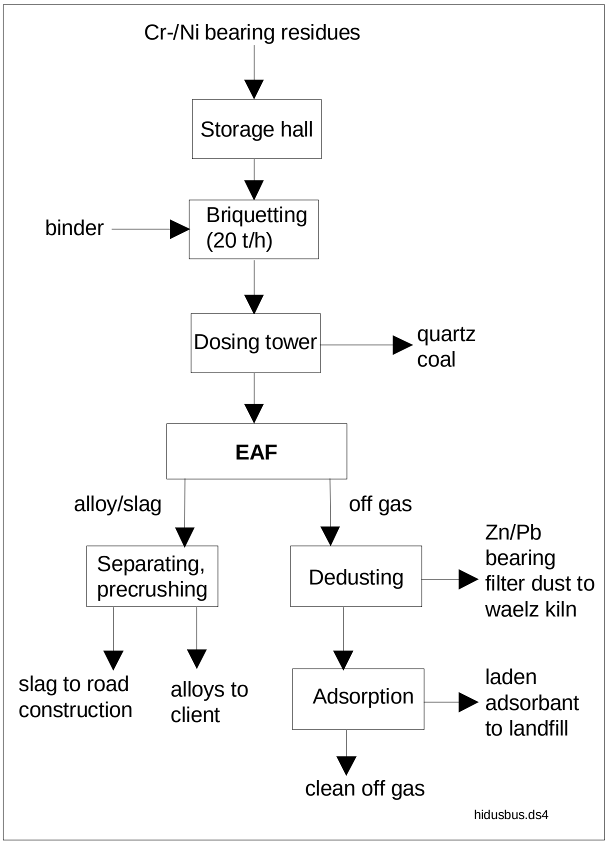

Figure 4-5: Processing scheme for high grade steel dust treatment

ScanDust treatment (S8)

Another process to treat high grade steel dusts, mainly from northern Europe, is the so-called *ScanDust* plasma process, operated in Sweden [45].

17 Information provided by industry (June 1997).

4.5.3 Treatment of refractory breaks

Refractory breaks treatment (S9):

The possibilities to reuse refractory breaks depend in general on the degree of purity of the material obtained from the furnace. Refractory breaks, that are not infiltrated by slags or steel melt, may be returned to the producers of refractory material in order to be recycled.[18] Also an internal reuse, eg. the charging into the EAF, is possible.

Strategies of German plants to treat refractory breaks (examples):

Some plants treat refractory breaks and return them to the refractory material producing industry. Also an internal use of refractory breaks is carried out [90].

4.6 Techniques concerning the medium water

Generally, water is only used in the EAF steelmaking processes in connection with non-contact cooling, and if a wet scrubbing technique for off gas cleaning is used [17]. As wet scrubbing is not applied in major German electric steelmaking plants any longer, this topic is not further investigated in the following. The most relevant use of water considered in this paper in an electric steelmaking plant is the water used for the cooling of the elements of the furnace. Additionally, some water may be used for the cooling of waste gas or in the secondary metallurgy section. The water needed with respect to the cooling elements amounts to 5-12 m^3(STP)/(m^2h) [90]. A share of this used water is possibly discharged. For requirements, that can be met by modern EAF plants, with respect to sewage caused by waste gas cooling or secondary metallurgy cf. Table 8-8 in the Annex.

Closed loop systems (W1):

Modern German plants operate with closed cooling systems in the EAF and secondary metallurgy sections. For this reason it can be assumed, that electric steelmaking in Germany does not impose adverse environmental impacts related to the medium water within the investigated limits.

Water use in German plants (examples):

Preussag Stahl AG, Peine, 100 t, 140 MVA: Closed loop system [90].

4.7 Techniques concerning noise aspects

Noise is a significant workplace problem within the iron and steel industry, especially when electric arc furnaces are in use. Typical noise levels for electric arc furnaces, given by the

[18] The amount of recycled refractory breaks effects the quality of the produced refractory material (i.a. standing time).

sound power level, are between 125 and 139 dB(A) [58]. This sound level is relatively independent of the furnace capacity. Often, the noise emitted from an EAF is also stated by the average sound pressure level, measured at a certain distance from the furnace. This figure is always 8-20 dB smaller than the sound power level [58].

The total noise resulting from electric steelmaking plants, perceived at a certain location, origins from several sources and depends on several factors. Relevant parameters are the installed transformer capacity, the size of the furnace, existing enclosures of the EAF and the melting shop, the operating conditions, the distance between emission and immission location, the way of propagation, the weather situation, and the conditions at the immission location. Further factors to take into account include the periods of operation of the plant (day/night-time) and the existing background noise at the immission site [43, 58].

Main noise sources within an electric steelmaking plant are the EAF itself (including the encapsulated transformer), the reloading works at the scrap yard, the gas cleaning system (precipitator including the fan motor), the water cooling system, and the traffic related to the transportation of the inputs and outputs.

The identification of factors that influence the noise emitted by several sources within an electric steelmaking plant usually helps to show potentials for the reduction of noise emissions. Furthermore, besides the investigation of the several emission sources, also the spectral composition of the noise is an important topic. Impulses or tonal components, i.e. the "information" contained in the noise, and not its level, frequently cause complaints at the receptor's site [58].

4.7.1 Aspects of relevant noise sources

A general approach to isolate the influence of certain emission sources on the overall emission level is inter alia to perform systematic measurements and to collect the data obtained in emission inventories [58]. In recent years, some research on the acoustic characteristics and the decisive factors for noise creation in electric steelmaking plants has been done.

For the electric arc furnace itself investigations showed the following factors to be relevant for noise creation [43]: Electrical power supply, related to the time elapsed since the beginning of the melting phase, the condition of the inputs, the physical state of the EAF (like the type of the brickwork, the sealing of hood and door, and electrode or other openings), the stage of the melt, and the configuration of the furnace. Different types of scrap also have an impact on the noise creation within the EAF. Smaller and more homogeneous pieces of scrap support a more stable burning of the arc and a lower noise level. The noise creation of the gas cleaning system is mainly influenced by its capacity, which is at last determined by the furnace size, the suction system (4th hole, secondary dedusting), the precipitation system (electrostatic precipitator, bag filter), and the design of the precipitator (pressure-, suction filter-, cleaning equipment) [43]. Main emission sources within the precipitation system are the waste gas fans, which emit sound power levels up to 120 dB(A), and auger-type or endless chain drives for the drag-out of dust, often causing squeaking sounds.

4.7.2 Noise abatement measures

Principally, noise created in electric steelmaking plants affects the workers in the plants, and, if a plant is located close to residential areas, inhabitants in the neighbourhood of the steelworks. Therefore, noise abatement measures should aim towards the reduction of both, the internal and the external impacts of the noise emissions created within an electric steelmaking plant.

Encapsulation (N1):
The protection of the workers close to the EAF can mainly take place by an acoustic encapsulation of the furnace and the furnace shop or the installation of noise protected pulpits, as primary measures to reduce noise creation in the furnace itself are not known, at the moment [43].

Muffling (N2):
Additional abatement measures like the muffling of windows, doors, gates, and ventilation openings or the construction of acoustical barriers are usually more relevant for the protection of the surroundings.

Acoustic barriers and further measures (N3):
Noise created at the scrap yard by the handling of scrap sometimes shows impulse peaks of up to 125-128(A) for 2 to 5 seconds. Acoustic barriers or berms close to the scrap yard may produce a noise reduction for the receptors of up to 8 dB. In cases, were a larger reduction of the noise is required, placing the scrap handling facilities in a building is the only feasible solution [58]. The construction of acoustical barriers can be applied as a retrofit measure, like it has been the case at Det Danske Stålvseværk [20]. Another noise source at the scrap yard is the whining noise produced by the transmission boxes of cranes. Even with sound power levels of only 105-112 dB(A) these noises may be perceived at considerable distances. An acoustic enclosure with a reasonable opening for the steel wires effectively reduces the high frequency components [58].

Further aspects:

The condition or shape of the inserted scrap also affects the noise created in the EAF. However, due to quality, process, and economic reasons it is not possible to charge light and homogeneous scrap just in order to reduce noise emissions by the EAF [43]. Significant reductions for the workers and also for the surroundings in the sound level can be achieved by an encapsulation of the furnace. But this may lead to handling problems, if the encapsulation fits to tight to the furnace. Another option is to separate the melt shop from the casting bay, which can reduce the sound level up to 30 dB [43]. The sound proofing of the buildings that contain the steelworks, in particular by using soundproof materials in construction and taking special care for acoustically weak points like doors or gates, has been common within the last years. Electric steelmaking plants that have been erected within the last years have been put up with separate melt shops including a roof hood suction system [43]. The sound power of a melt shop that is sound proven in a suitable manner can be reduced to 90 to 100 dB [58]. VAI has developed a furnace encapsulation (cf. footnote 7), which even reduces the noise level within the frequency spectrum from 20-10,000 Hz from about 90 dB(A) to below 65 or lower over the whole spectrum [96].

Bag house fans also may produce a considerable level of noise. Fans operating with a pressure increase of 300 dePa and an air flow of 500,000 to 1,500,000 m^3(STP)/h produce a sound power level of 125 to 135 dB(A) in the inlet and outlet duct. The casing of the fan itself produces levels between 117 and 127 dB(A). Enclosures for the fan with an insertion loss of 20-40 dB can reduce the problem. In some cases, there may be the necessity to encase the baghouse, eg. if the distance to the neighbours is short and the impulses by the bag cleaning system are audible [58].

German electric steelmaking plants are subject to regulations concerning the limitation of noise immissions imposed on the neighbourhoods [5]. The plants usually have to comply with requirements that are set by licensing authorities. Standard values, that are the basis for actual requirements are shown in Table 4-6 [5].

Table 4-6: Standard values for maximum noise immissions at the immission site

Area of application	Day-time	Night-time
Areas, which only accommodate industrial installations or housing for owners and managers of installations and supervisory staff or stand-by staff	70 dB(A)	70 dB(A)
Areas, which mainly accommodate industrial installations	65 dB(A)	50 dB(A)
Areas, which mainly accommodate industrial installations or housing, but within which neither industrial installation nor housing are located mainly	60 dB(A)	45 dB(A)
Areas, which mainly accommodate housing	55 dB(A)	40 dB(A)
Areas, which only accommodate housing	50 dB(A)	35 dB(A)
Dedicated health resorts, hospitals, nursing homes	45 dB(A)	35 dB(A)
Housing, that is directly connected to the installation	40 dB(A)	30 dB(A)

4.8 Case studies of modern EAF plants

To show the effects of the above mentioned techniques on EAF operation and environmental performance, in particular with respect to air pollution, data of modern EAF plants is provided in the following.

4.8.1 Example A

Figure 4-6 depicts the gas cleaning system of an EAF plant with AC furnace technology and 85 t capacity, using a combination of a direct extraction device (4th hole) and a hood system for waste gas collection. An evaporation cooling system is used to reach the required entrance temperature for the fabric filter.[19] This cooling system is cooling down the waste gas stream rapidly to prevent a de novo synthesis of dioxins. The bag-house contains about 2880 single fabric filters providing a total filter surface of 28,800 m^2, achieving a dust content in the flue gas below 5 mg/m^3(STP). A gas cleaning technology of this kind also makes it possible to lower dioxin and furane emissions down to a level of about 0,1 ng TE/m^3 (STP) [97].

[19] Depending on the filter material, eg. polyester or polyamid, the maximum entrance temperature may vary between 130°C-280°C [78].

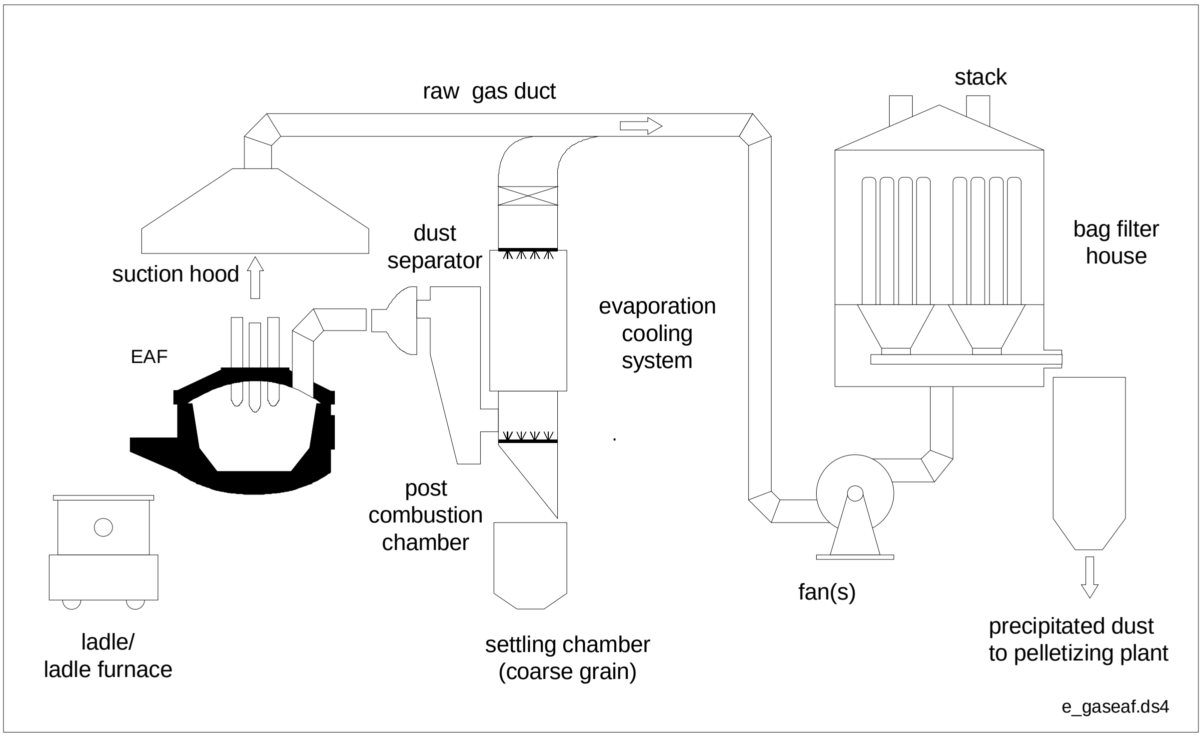

Figure 4-6: Gas cleaning system of a German electric steelmaking plant

Table 4-8 depicts data on waste gas composition and temperature of this plant (Example A1: normal operation, Example A2: operation with additional air quenching). The plant produced about 140 kg/t of EAF slag on average, the slag composition can be found in [98] and Table 3-2.

A specific input/output balance of this modern German electric steelmaking plant, producing commercial steel, is provided in Table 4-7 (average for normal operation conditions).

Table 4-7: Specific input/output balance of steelmaking plant (Example A)

Input (specific)		**Output (specific)**	
Ferrous scrap [kg/t]	1,125	Steel melt	1,000
Electrical energy [kWh/t]	360	Slag yield [kg/t]	139,7
Oxygen [m^3 (STP)/t]	31.25	Precipitated dusts [kg/t]	14
Natural gas [m^3 (STP)/t]	4.375	Refractory breaks [kg/t]	n.a.
Coal [kg/t]	7.5	Waste gas flow [m^3/h]	1,200,000
Graphite electrodes [kg/t]	2.2		
Lining [kg/t]	12.8		

4.8.2 Example B

Table 4-8 also shows another two analyses of the clean gas composition of another German EAF steelmaking plant. This furnace uses a post combustion chamber, quenching, and a bag filter for air pollution control.

Table 4-8: Clean gas composition of modern German EAF plants

Substance	Unit	TA Luft	Example A1	Example A2	Example B1	Example B2
			Sum	Sum	Sum	Sum
Total dust	mg/m^3 (STP)	20	5	1	1.2	1.2
Class 1 dust-like inorganic substances						
Cadmium (Cd)	µg/m^3 (STP)	sum 200	2.3	0.5	23	141
Mercury (Hg)	µg/m^3 (STP)		0.3	<0.1	22	13
Thallium (Tl)	µg/m^3 (STP)		<0.1	<0.1	n.a.	n.a.
Class 2 dust-like inorganic substances						
Arsenic (As)	µg/m^3 (STP)	sum 1000	2.7	<1.7	7	6
Cobalt (Co)	µg/m^3 (STP)		<0.2	<0.2	<19	<17
Nickel (Ni)	µg/m^3 (STP)		0.5	<0.3	<9	<8
Selenium (Se)	µg/m^3 (STP)		<1.8	<2.2	n.a.	n.a.
Class 3 dust-like inorganic substances						
Lead (Pb)	µg/m^3 (STP)	sum 5000	164.1	36.1	254	181
Chromium (Cr)	µg/m^3 (STP)		8.4	1.1	<19	<17
Copper (Cu)	µg/m^3 (STP)		9.7	<1.7	221	162
Manganese (Mn)	µg/m^3 (STP)		56.7	<7.3	33	25
Vanadium (V)	µg/m^3 (STP)		<0.7	<0.9	<19	<17
Tin (Sn)	µg/m^3 (STP)		3.8	<2.2	<19	<17
Vaporous or gaseous inorganic substances						
Fluor as HF	mg/m^3 (STP)	5	<0.05	<0.05	0.1	0.1
Chlorine as HCl	mg/m^3 (STP)	30	1.2	<0.3	<0.18 (chlorine)	<0.19 (chlorine)
Sulphur dioxide (SO_2)	mg/m^3 (STP)	500	8	11	5.6	3.8
NOx (NO_2)	mg/m^3 (STP)	500	20	18	8	8
Carbon monoxide (CO)	mg/m^3 (STP)	minimize	164	275	57	64
Carcinogenic substances						
Benzopyren	µg/m^3 (STP)	100	0.015	0.002	0.11	0.03
Dibenzanthracen	µg/m^3 (STP)	100	0.006	<0.003	0.03	0.01
PAH (EPA)	µg/m^3 (STP)		n.a.	n.a.	83.18	39.50
Benzol	µg/m^3 (STP)	5	298	251	n.a.	n.a.
Organic substances						
Total Carbon (C)	mg/m^3 (STP)	minimize	4	3	<3	5
Dioxins and furanes (PCDD/F)	ng TE/m^3 (STP)		0.144	0.034	0.07	0.04
PCB	µg/m^3 (STP)		1.058	0.475	0.33	0.14
Volume rate (waste gas)	m^3 (STP)/h		~1,200,000	~1,200,000	~1,400,000	~1,400,000
Temperature (clean gas) (T)	°C		71	69	n.a.	n.a.

Sources: [90, 98]

5 Best available techniques

5.1 Introduction

According to the IPPC-Directive, the practicable assessment of available techniques for each industry sector with regard to all environmental media is required in order to identify the best available techniques. Since the member states and the relevant working groups have not yet agreed on a particular evaluation method, this chapter aims to propose best available techniques on basis of the existing data of chapter 4, taking into account the most important provisions laid down within the Annexes III and IV of the IPPC-Directive. Due to the lack of a suitable evaluation method, the techniques are assessed qualitatively on the basis of verbal argumentation.

5.2 Procedure for the identification of BAT

As long as no settled on evaluation method for the determination of BAT exists, and due to the facts that often rather vague data is available, a preliminary identification is viable, based on qualitative statements. Not all of the numerous requirements of the Annexes III and IV of the IPPC-Directive can be dealt with sufficiently, at the moment. The pursued dissemination is oriented at Table 5-1.

Table 5-1: Survey of environmental aspects to be considered for the identification of best available techniques in the secondary steelmaking industry

Medium	Part of the process	Remarks
Air	Raw material handling and storage	list the different substances and the arising amounts
	Charging and tapping	- " -
	Melting	- " -
	Oxidising	- " -
	Refining	- " -
	Secondary metallurgy	- " -
	Cross media effects	- " -
Water	Analogous parts of the process	- " -
	Cross-media effects	- " -
Soil/Waste/ Raw material	Deposition of waste	Classify according to the quality of waste (green/red list, type of tip site), amounts
	Recycling of waste	Type of recycling (as building material, in the non-ferrous metal industry), marketability, amounts
	Use of raw materials	amounts, quality
Energy	Energy consumption	Differentiate between the types of energy (gas, oil, electricity, coal, etc.)

The economic aspects (investments, operational costs) are not considered in this preliminary identification of BAT, since the IPPC-Directive mainly aims at the environmental benefits and only on a later step refers to the economic side. Since the quantitative evaluation might not be satisfying, a more structured approach might be desirable. Especially for the numerous facts that have to be considered, a structured decision support should guide the process of identifying the best available techniques, particularly with regard to cross media impacts. A general scheme for an assessment method for the identification of BAT in accordance with the requirements of the IPPC-Directive may comprise three steps:[20]

- First screening,
- Examination, and
- Decision support.

A **first screening** of the available techniques aims to reduce the number of techniques to be investigated. Techniques that are especially qualified could be stated as BAT immediately, while processes, which do eg. not comply with certain standards, like emission limits laid down in EU legislation or other international agreements, are excluded from being BAT. The criteria in order to group techniques can be laid down systematically in decision trees, to make the evaluation procedure more transparent.

Next step of the evaluation procedure, if necessary, is a closer **examination** of the mass and energy flows of the relevant techniques. If not all process and emission data is relevant for the identification of BAT, the most important environmental aspects might be selected, furthermore. Especially cross-media effects should be investigated thoroughly.

If too numerous aspects are to be considered simultaneously, such that the identification of BAT is ambiguous, the use of a formal method for **decision support** is advisable in order to structure the data in an uniform manner. This approach fosters a transparent and understandable decision. If no exact figures are available, well defined statements like „high environmental relevance“, „no effects“, etc. could facilitate the evaluation.

5.3 Identification of BAT

This section identifies techniques that can be considered best available corresponding to important provisions of the IPPC-D, in particular Annex IV of that document, with the reservation mentioned in chapter 5.1 and 5.2.

[20] This question is being dealt with in a project at the German Federal Environmental Agency (Umweltbundesamt Berlin, UBA), that accompanies the work on this BAT notes.

5.3.1 Relevant aspects

Important considerations to be taken into account according to the IPPC-D (cf. Chapter 1) include the consumption of nature, raw materials and energy, the nature and volume of emissions into the different media, the use of low-waste technology, as well as the furthering of recovery and recycling of substances generated and used in the processes. Also the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it should be taken into account.

5.3.2 Identification of important aspects for secondary steelmaking

Transferring these relevant aspects to the secondary steelmaking industry, the following facts have to be taken account of:

- Use of raw materials (scrap, additions, fluxes, fuels),
- Energy consumption, efficiency, and recovery of the processes,
- Use of low-waste technology,
- Emissions into air from the EAF (in particular dust, CO, VOC, and dioxin emissions),
- Emissions into air from the secondary metallurgy processes (see above),
- Slag releases into soil by the EAF,
- Slag releases into soil by the secondary metallurgy processes,
- Handling of precipitated dusts arising from waste gas cleaning,
- Handling of refractory breaks,
- Furthering of recovery and recycling of slags, precipitated dusts, and refractory breaks,
- Emissions into water caused by the electric steelmaking process,
- Other impacts on the environment, for example by noise or odour.

5.3.3 Proposal for BAT

In consideration of the first scrutiny of chapter 4, the following technologies and techniques are proposed to be BAT with respect to integrated pollution prevention and control. Where possible, figures for the levels of achievable emissions have been supplied. It has to be carefully checked on a plant by plant basis for the retrofit measures mentioned, if the proposed BAT are not only reasonable for new plants, but also for existing plants.

General aspects (including energy efficiency):
With respect to the efficiency of use of raw materials and energy, a modern EAF, either equipped with high power or UHP AC or DC technology and a sensible combination of the measures G1-G8 is proposed to be BAT. Waste heat arising at waste gas cooling or furnace cooling should be recovered, if possible, for steam production or district heating.

Air:

Next to process integrated measures like (U)HP operation and automation (G1, G7), which can help to reduce emissions into the air, the following air pollution abatement scheme is proposed: (1) Collection of emissions into the air by the EAF, the secondary metallurgy devices, as well as tapping and charging operations by a combination of the measure A1 and an appropriate selection of the measures A2-A4, such that on the one hand no significant amount of emissions is released to the environment, and on the other hand the working staff in the furnace area is not subject to hazardous concentrations of dust, heavy metals and other substances. (2) Post combustion and quenching of the waste gas to support a complete combustion of the waste-gas. (3) Gas cleaning by means of fabric filters, i.e. a bag house, to achieve to the greatest possible extent the lowering of the clean gas dust content and a minimisation of PCDD and PCDF.

An electric steelmaking plant using the mentioned techniques is considered to achieve a clean gas composition that fulfils at least the following requirements[21]:

Table 5-2: Proposed reference values (air)

Substance	Unit	Proposal
Total dust	mg/m^3 (STP)	5
Inorganic substances		
Cadmium (Cd)	mg/m^3 (STP)	*0.002*
Mercury (Hg)	mg/m^3 (STP)	*0.2*
Thallium (Tl)	mg/m^3 (STP)	*0.002*
Arsenic (As)	mg/m^3 (STP)	*0.02*
Cobalt (Co)	mg/m^3 (STP)	*0.02*
Nickel (Ni)	mg/m^3 (STP)	*0.02*
Selenium (Se)	mg/m^3 (STP)	*0.02*
Lead (Pb)	mg/m^3 (STP)	*0.15*
Chromium (Cr)	mg/m^3 (STP)	*0.15*
Copper (Cu)	mg/m^3 (STP)	*0.15*
Manganese (Mn)	mg/m^3 (STP)	*0.15*
Vanadium (V)	mg/m^3 (STP)	*0.15*
Tin (Sn)	mg/m^3 (STP)	*0.15*

Substance	Unit	Proposal
Vaporous or gaseous inorganic substances		
Fluor as HF	mg/m^3 (STP)	*1*
Chlorine as HCl	mg/m^3 (STP)	*2.5*
Sulphur dioxide (SO_2)	mg/m^3 (STP)	*minimize*
NOx (NO_2)	mg/m^3 (STP)	*30*
Carbon monoxide (CO)	mg/m^3 (STP)	*250*
Carcinogenic substances		
Benzopyren	mg/m^3 (STP)	*0.01*
Dibenzanthracen	mg/m^3 (STP)	*0.01*
Benzol	mg/m^3 (STP)	*0.002*
Organic substances		
Total Carbon (C)	mg/m^3 (STP)	*20*
Dioxins and furanes (PCDD/F)	ng TE/m^3 (STP)	0.1
PCB	$\mu g/m^3$ (STP)	*1*
normal: recommendations, *cursive: proposals*		

21 Requirement laid down recently by German authorities for new installations.

Soil:

Slags should be treated for re-use, most likely in the construction area. While an almost complete use of EAF slags seems to be possible, the re-use potential of slags arising at secondary metallurgy processes has to checked on a plant by plant basis. For the handling of precipitated dusts a recovery of the metal content of the dusts is proposed. This can be performed by a suitable recovery process for both, commercial and high grade steel dusts. Options for the handling of refractory breaks need to be evaluated on a plant by plant basis.

Water:

The only relevant use of water in an electric steelmaking plant within the scope of this study is for cooling purposes. For this use, a closed loop cooling system for the EAF is proposed to be BAT. Additionally, some water may also be used for gas cooling or secondary metallurgy. Requirements for possible discharges by these processes are proposed in Table 5-3.

Table 5-3: Proposed reference values (water)

Hazardous Substances	Gas cooling and secondary metallurgy of crude steelmaking
Chemical Oxygen Demand COD	50 mg/l
Iron	5 mg/l
Lead	0.5 mg/l
Chromium, total*	0.5 mg/l
Nickel*	0.5 mg/l
Zinc	2 mg/l
Fish toxicity as thinning factor	2
*: Only for the production of chromium and nickel containing steel	

Noise:

Noise emitted by electric steelmaking plants should be muffled in such a way, that it does not cause higher sound power levels at the receptors site than the ones presented in Table 5-4.

Table 5-4: Proposed reference values (noise)

Area of application	Day-time	Night-time
Areas, which only accommodate industrial installations or housing for owners and managers of installations and supervisory staff or stand-by staff	70 dB(A)	70 dB(A)
Areas, which mainly accommodate industrial installations	65 dB(A)	50 dB(A)
Areas, which mainly accommodate industrial installations or housing, but within which neither industrial installations nor housing are located mainly	60 dB(A)	45 dB(A)
Areas, which mainly accommodate housing	55 dB(A)	40 dB(A)
Areas, which only accommodate housing	50 dB(A)	35 dB(A)
Dedicated health resorts, hospitals, nursing homes	45 dB(A)	35 dB(A)
Housing, that is directly connected to the installation	40 dB(A)	30 dB(A)

Further aspects:

Aspects, that also need to be considered when determining BAT for electric steelmaking plants are requirements for raw materials, safety considerations, vibration aspects, and required measures after the cessation of installations and their de-commissioning. However, due to insufficient data, these aspects have not been included in this study, at the moment. Nevertheless, they should be addressed in a BREF.

6 Emerging techniques

6.1 General developments in modern production technology (including energy aspects)

6.1.1 Preheating of scrap

Scrap preheating using waste gas (GE1):

To improve the energy balance and therefore the productivity of the EAF process, preheating of scrap using waste heat from primary off gas is a promising technical means, if organic emissions can be controlled. Scrap preheating by additional burners is also performed, but requires additional energy input. It bases on the physical principles of heat radiation, convection of gases, heat transfer, and heat transport. Environmental problems related to organic emissions possibly arise from contaminated scrap. Conventional scrap preheating systems are not able to comply with German legislation, at the present time. For this reason, no scrap preheating installations are operated in Germany. New developments in scrap preheating technology try to overcome in particular the problems related to organic contamination of scrap by an exact control of the temperature profile in the furnace [88]. For new developments related to scrap preheating cf. [15, 65], as well as the following section.

6.1.2 New furnace concepts

In recent years a number of new furnace types have been introduced, that might be considered to be candidate BAT within a short period of time. Furnaces belonging to this category are presented in the following.

Comelt EAF (GE2):

The Comelt furnace is an EAF on a DC basis with side electrodes provided by VAI [9, 10]. In most cases the furnace is featured with four slanted electrodes, resulting in electric energy transmission by four inclined DC arcs. Other features of this concept are integrated shaft scrap preheating, a complete off gas collection in each operating phase and a lowered sound level. The essential advantages, according to the manufacturer, are

- High productivity (tap-to-tap times of less than 45 min),
- Reduction of total energy consumption by integrated scrap preheating (appr. 100 kWh/t compared to conventional EAF),
- Reduction of electrode consumption (approximately 30%),
- Complete off gas collection at all times and a reduction of off gas volume by up to 70%,
- Reduction in maintenance costs due to a simpler plant design,

- Reduced noise level by up to 15 dB(A).

State of Development / Realisation:
A pilot electric arc furnace using the Comelt melting principle has been implemented and investigated by revamping a 50 t plasma primary melting furnace in the former LD steel shop in Linz [10, 9].

Contiarc furnace (GE3):
The Contiarc electric arc furnace is a continuously operating annular shaft furnace with a central DC electrode, though in principle it can also be heated by alternating current [77]. The shaft, consisting of an outer and an inner vessel, is charged continuously with scrap. By doing so, the scrap is preheated by ascending hot furnace gases (integrated high temperature scrap preheating). This concept with tapping during the melting operation reaches a power-on time of almost 100%. Further advantages according to the furnace providers (Mannesmann Demag) are:

- Reduced energy losses (200 kWh/t less than with conventional furnace systems),
- Waste gas and dust volumes are considerably reduced (waste gas: 150,000 m^3(STP) to 900,000 m^3(STP); dust content: up to 40% less for a 100 t/h Contiarc furnace) requiring a lower capacity of the gas cleaning system and also lower electric power consumption (23.1 kWh/t),
- Gas-tight furnace enclosure captures all primary and nearly all secondary emissions,
- Advantages in production costs,
- Reduced electrode consumption (DC furnace: 0.8 kg/t less than AC furnace).

State of Development / Realisation:
A pilot electric arc furnace has been implemented and investigated at the laboratory of RWTH Aachen; as a next step a demonstration plant is planned [77].

Energy Optimised Direct Current Twin Electric Arc Furnace (EODC-TEAF, GE4):
The EODC-TEAF [88] is equipped with two shells, which are alternately supplied by one electric power supply system. While one shell is in melting operation, the second is used for tapping, setting up and charging. In addition, the scrap charged in the non-melting furnace is preheated up to 550 °C using oxygen and carbon lancing. Thereby organic pollutants contained in the scrap are burned using the chemical reaction energy for scrap preheating. The EODC-TEAF is especially suitable for melting scrap of minor quality. The main advantages of this concept, as described by the providers (ABB), are:

- The double shell concept allows a reduced tap-to-tap time of about 42-43 min and an increase in productivity of about 40%,

- The furnace is suitable for charging scrap with lower quality,
- The post combustion integrated in the furnace reduces the electrical energy consumption.

State of Development / Realisation:
The first EODC-TEAF will be in operation in April 1997 in Malaysia. Each shell has a diameter of 6.1 m and a tapping capacity of about 85-95 t. The furnace will be operated with a hot heel of 20-30 t. The annual output will be 900,000 tons of raw steel.

Double shell furnaces (GE5):
The concept of double shell furnaces aims to reduce power-off times of the electrical system in an electric steel plant, and therefore to increase productivity. Usually, two furnace shells are build next to each other, close to a swivelling electrode arm that can be used to melt the scrap in both vessels sequentially. By using this technology power-on time of the electrical system has been increased in some plants considerably (up to 92%) and as a consequence tap-to-tap time has been reduced (about 79 minutes for 2 heats) [66]. To actually benefit from the reduced tap-to-tap times and increased productivity, the furnace has to be optimised from the energy point of view, as energy losses in the empty vessel at least partly offset the advantages of higher productivity [88]. However, a considerable number of recently realised installations of optimised double shell furnaces seems to suggest, that this technology has some potential to be examined further [31, 66, 81, 88].

6.2 Techniques concerning the medium air

6.2.1 Injection of adsorbents

Lignite coke:
Lignite coke may serve to reduce dioxin/furane concentration, if it is given as an adsorbent to the waste gas flow [21].

6.3 Techniques concerning the medium soil

6.3.1 BSW treatment (SE1)

The BSW process can be used for recovery of zinc and lead from metallurgical-works dust. A schematic view of the process is shown in figure 6-1. BSW GmbH plans to erect a 25,000 t/a plant, using the self developed BSW-process, for the treatment of its EAF dusts. Main components of this plant are three rotary kilns operated within different temperature intervals (300-600 °C, 1,000-1,100 °C, 1,150-1,350 °C) [27, 71]. Products of this residue free process are zinc oxide, alkali/lead-chloride, and iron pellets.

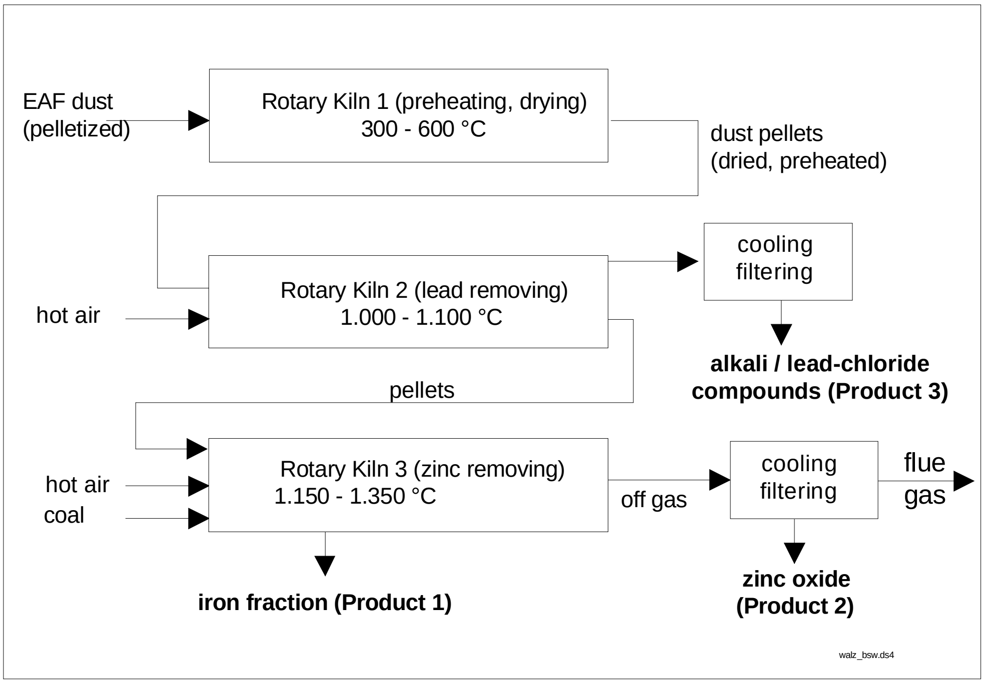

Figure 6-1: Schematic view of the BSW-process for treatment of EAF dusts

Source: following [27]

7 Annex

7.1 Additional information on current legislation relevant for the secondary iron and steel industry

7.1.1 Introduction

There are various regulations concerning environmental standards to comply with related to the erection and operation of electric arc steel production plants, since the iron and steel industry is a major source of air and water pollution and generates large quantities of waste materials. Consequently, the immediate environmental concerns are the control of air pollution (particularly CO, CO_2, SO_x, NO_x and heavy metals), solid waste disposal and recycling, waste water treatment and - more recently with the increased amounts of recycled contaminated scrap metals - dioxin emissions.

The last years have seen a world-wide change in the environmental policy. The fundamental premise of the new concepts is that pollution problems should be addressed in an integrated manner that takes into account all three environmental media (air, water, soil), because the single medium focus may result in the transfer of pollution to the other media. A recommendation adopted by the OECD [73] advises member countries to:

Practice integrated pollution prevention and control, taking into account the effects of activities and substances on the environment as a whole and the whole commercial and environmental life cycles of substances when assessing the risks they pose and when developing and implementing controls to limit their release.

As mentioned above, existing regulations cover:

- air quality,
- water quality,
- waste management and disposal of hazardous materials.

The following section gives complementary information on chapter 2.2.1.

7.1.2 Regulations on an international level

Besides the EC-Directives cited in chapter 2.2.1, the following international regulations are relevant for the German secondary iron and steel industry.

Framework Convention on Climatic Change (FCCC):

The Community ratified the Framework Convention on Climatic Change (FCCC) at the UNCED Conference in Rio in 1993. The FCCC includes commitments for developing countries to reduce their emissions of CO_2 and greenhouse gases. Technologies inducing an important increase of energy consumption should be avoided. Member states of the European Community have to meet the international agreements described below.

HELCOM:

The „Convention on the Protection of the Marine Environment of the Baltic Sea Area" was signed by the seven Baltic Sea States in 1974 and entered into force in 1980. The decisions by the Helsinki Commission (HELCOM) reached unanimously are regarded as recommendations to the governments concerned, and be incorporated into the national legislation of the Parties of the Convention. Mainly the HELCOM recommendations 11/5 and 11/7 address the iron and steel industry.

HELCOM recommendation 11/5 aims at restrictions of discharges from the iron and steel industry with regard to water and waste. It demands that closed systems should be developed to circulate process and cooling water to at least 90%. The objectives for total discharges are set for EAF at 20 mg/l of sulphur, and no limits are set for oil, zinc and lead.

The draft recommendation to supersede HELCOM recommendation 11/5 foresees for EAF objectives for total discharges of suspendible solids at 10 mg/t, for oil at 5 mg/l and for CNvol at 0.1 mg/l. The proposed BAT to reduce waste water discharges from the iron and steel industry suggests:

- Discharges should be avoided where possible by using dry operations (eg. gas cleaning techniques which cause no discharges to water);
- Process water, polluted cooling water and polluted stormwater should be treated separately from unpolluted cooling water at each point;
- Installation of closed water systems should be developed for process water, polluted cooling water and polluted stormwater;
- Production processes, utilisation of by-products, waste- and stormwater technology should be developed in order to minimize discharges (eg. slag granulation by process water);
- Sludge should be disposed of in a manner causing minimal environmental hazard.

HELCOM recommendation 11/7 suggests measures aiming at the reduction of emissions to the atmosphere from the iron and steel industry:

- Fugitive emissions from all processes should be avoided as far as technically feasible (eg. by encapsulation, evacuation hoods combined with good housekeeping practices);

- Fabric filters or technology environmentally equivalent should be used for dust cleaning eg. on sintering plants, for secondary gases from blast furnaces and basic oxygen furnaces, in EAF and at cutting and grinding operations;
- Low emissions coke cooling techniques, perferably dry quenching, should be used for new installations and from 1995 for existing coke plants;
- Filling gases from coke plants are to be conveyed to the crude gas as far as possible. Filling gases which may not be passed on shall be burned;
- Waste gases from coke oven pushing shall be captured and passed through a dust collector.

Objectives for emissions into the atmosphere with relevance for the secondary iron and steel industry are listed in Table 8-1.

Table 7-1: Objectives for emissions into the atmosphere with relevance for the secondary iron and steel industry laid down in HELCOM recommendation 11/7

Measures	Limits
Particulate matter content of filtered gases (when suggested technologies are used)	< 10 mg/m³ (STP)
Particulate matter content of filtered gases (in any case)	< 50 mg/m³ (STP)

PARCOM:

The Paris Commission (PARCOM) was established to administer the „Convention for the Prevention of Marine Pollution from Land-based Sources“ in 1974 (the "Paris Convention"). The Commission regulates and controls inputs of substances and energy to the sea via the atmosphere and from land-based sources: Rivers, pipelines, direct discharges and also offshore platforms. The Commission has undertaken a thorough review of a number of industrial sectors in order to establish the best available techniques to avoid pollution from those sectors and entered into force in 1978.

Especially the PARCOM recommendations 90/1, 91/3 and 92/3 give details for the secondary iron and steel industry, which can be found in Table 8-2 [76].

Table 7-2: List of BAT Recommendations for Iron and Steel Industry by PARCOM

90/1 on the definition of BAT for the secondary iron and steel plants

- Fume collection by dog-houses, local moveable hoods or total building evacuation at EAF's and converters;
- Fabric filters or equally efficient arrestment system for dust cleaning of process gases and secondary gases from EAF and converters;
- Fabric filters for dust cleaning or equally efficient arrestment system at cutting, grinding and scarfing operations;
- Regeneration of pickling baths and closing of rinse water systems;
- Addition of hydrogen peroxide to pickling baths containing nitric acid or any equivalent measure which enables reduction of NO_x to the atmosphere;
- Sedimentation combined with filtration of waste water from continuous casting and rolling. Recirculation or re-use of the water;
- Metal recovery from filter dust.

91/3 on measures to be taken and investigations to be carried out in order to reduce pollution from secondary iron and steel production

- Cadmium and mercury in all products that can end up as scrap. Plans and measures and timetables for further reduction by 1 January 1994.
- Chlorinated compounds in used scrap. Proposals to reduce the use of chlorinated oils and emulsions and timetable by 1 January 1994.
- The situation regarding mercury and dioxins emissions should be presented by Contracting Parties by 1995.
- Further research and development should be carried out to achieve suitable technologies of mercury and dioxins. The current state of development of such technologies should be presented by 1996. A timetable for the reduction of such emissions using these technologies should also be presented by the same date.

92/3 concerning limitations of pollution from new secondary iron and steel production and rolling mills

- Atmospheric Emissions

1. As much dust as possible, including fugitive dust, should be collected from process gases. Dust concentrations less than 20 mg/m^3 after filtration should be achieved by using fabric filters, or equally efficient arrestment system, for dust cleaning. If dust contains hazardous substances, lower standards should be achieved.
2. Electric arc furnace shops should be constructed and maintained in such a way that total dust emissions, including dust escaping through skylights should not exceed 150 g/tonne produced steel for each steel plant.
3. Measures should be taken to reduce NO_x emissions at pickling plants where nitric acid is used and NO_x emissions (as NO_2) exceed 5 tonnes/year. The measures should aim at a reduction rate of at least 70 per cent.

- Aqueous Discharges

4. At least 95% process water (i. e. water form direct cooling) should be recirculated from hot rolling and continous casting machines.
5. The discharges of suspended solids (SS) and oil in bleed from process water systems should not exceed the following values (in g/tonne processed steel): continous casting (SS = 10 and oil = 5); hot rolling (SS = 50 and oil = 10); cold rolling (SS = 10 and oil = 5). For plants with integrated wastewater systems, the total annual discharges should not exceed the sum of the annual production multiplied with the values above for each process.
6. Waste water flow from pickling and plating should be reduced as far as possible. Discharges of metals from pickling plants should be limited as follow: Ni = 1 mg/l; Cr-tot = 1 mg/l; Cr (VI) = 0,1 mg/l; Zn = 2 mg/lS; S Cd = 0,2 mg/l.
7. In pickling plants using more than 20 tonnes of nitric acid per year, measures should be taken in order to reducer the nitrate discharges by applying acid regeneration, or equally efficient method.

- Waste

8. Recovery of metals from all zinc-rich (zinc concentration above 16%) filter dust from all stainless steel production should be carried out.

It should be noted that BAT notes from PARCOM or HELCOM are only recommendations and there is no obligation on the Contracting Parties to comply with them. The Convention for the Protection of the Marine Environment of the North-East Atlantic ("OSPAR Convention") will enter into force when it has been ratified by all of the Contracting Parties to the present Oslo or Paris Conventions and will replace the Oslo and Paris Conventions, but Decisions, Recommendations and all other agreements adopted under the present Conventions will continue to apply.

Agreements on the pollution prevention in the River Rhine:
Two international agreements dating from 1978 concern the pollution prevention of the river Rhine aiming at chemical contamination and chlorides [89].

Long Range Treaty on Air Pollution (LRTAP):
International efforts to reduce the adverse effects of transboundary acidification on forests, aquatic ecosystems, and human health, by way of internationally co-ordinated emission reductions, were undertaken in the 1979 Convention on Long Range Transboundary Air Pollution (LRTAP). After coming into force in 1983, the LRTAP Convention was augmented by (1) the 1984 Protocol on long-term financing; (2) the 1985 Helsinki Protocol reducing sulphur emissions or their transboundary fluxes by at least 30%; (3) the 1988 Sofia Protocol on the freeze of the emission of nitrogen oxides; and (4) the 1991 Geneva Protocol on the control of emission of volatile organic compounds.

Basel Conventions:
The Basel Conventions declare the responsibility of OECD states on the control of transboundary movements of hazardous wastes and their disposal. It was adopted in March 1989 and entered into force in May 1992. 88 countries plus the EC are Parties to the Convention. The conventions comprise Technical Guidelines for waste management activities.

A three-tiered system is proposed to delineate controls to be applied to transfrontier movements: Wastes destined for recovery operations included on the green list shall move among OECD Member countries toward recovery operations subject to all existing controls normally applied in commercial transactions. Wastes destined for recovery operations included in the amber list or red list shall be subject to the stricter or most rigorous controls. A decision adopted by the Parties in 1994 prohibits with immediate effect the export from OECD countries of hazardous wastes destined for final disposal in non-OECD countries. The decision also phases out similar exports destined for recycling or recovery operations before banning them completely on 31 December 1997.

WHO / UNEP:

UNEP and WHO operate the GEMS (Global Environment Monitoring System) environmental pollution monitoring programmes for urban air quality (AIR), food, human exposure assessment location (HEAL), and water. The objectives of GEMS as defined at its inception are:

- to strengthen monitoring and assessment capabilities in the participating countries,
- to increase the validity and comparability of environmental data and information,
- to produce global/regional assessments in selected fields and compile environmental information at the global level.

7.1.3 Regulations on a German level [22]

Table 8-3 gives an overview of the German legal basis and regulations for environmental protection in Germany alongside the product line. In the following, the most important acts and regulations concerning air and water quality are presented.

Table 7-3: Legal basis and regulations alongside the product line

Area	Legal Basis	Regulations and ordinances
Transport	Verkehrsrecht	Gefahrgutverordnung Straße Gefahrgutverordnung Schiene Gefahrgutverordnung Binnenschifffahrt
Health and safety at work	Chemikaliengesetz (ChemG)	Chemikalienverbotsordnung Gefahrstoffverordnung
	Gewerbeordnung	TA Lärm Arbeitsstättenverordung und -richtlinien
Emissions	Bundes-Immissionsschutzgesetz (BImSchG)	Bundes-Immissionsschutzverordnungen Bundes-Immissionsschutzverwaltungsvorschrif-ten TA Luft TA Lärm
	Wasserhaushaltsgesetz (WHG)	Katalog wassergefährdender Stoffe Abwasserverwaltungsvorschriften Indirekteinleiterverordnungen der Länder
Treatment	Abfallgesetz (AbfG)	Abfall- und Reststoffüberwachungsverordnung Abfallbestimmungsverordnung Reststoffbestimmungsverordnung TA Abfall TA Siedlungsabfall
	Kreislaufwirtschaftsgesetz (KrW.-/AbfG)	

[22] This section provides more detailed information on the German legal framework than chapter 2.2. However, a complete discourse on all the regulations is not intented in this study. The regulations may be found in corresponding laws, ordinances, or other documents.

7.1.3.1 German regulations concerning the air quality

The Federal Immission Control Act (BImSchG) is the basic law for air pollution and noise abatement. It is supplemented by the ordinances and technical instructions on air quality and on noise.

Federal Immission Control Act (Bundes-Immissionsschutzgesetz BImSchG):
The legal instrument for monitoring air pollution is the Federal Immission Control Act (Bundes-Immissionsschutzgesetz: BImSchG). The definition of immissions comprises besides air pollutants noise, vibration, light, heat, radiation and associated factors affecting humans as well as animals, plants or other things. With this concept, the idea of cross-media effects is already implemented to a certain extent. The BImSchG required federal authorities to (a) issue ordinances identifying the types of facilities which are subject to licensing, (b) set licensing requirements for these facilities, and (c) impose emission limit values and technical control requirements for all facilities, whether licensed or not.

Especially article 5(1)3 BImSchG aims at the avoidance and minimisation of wastes and residues, explicitly inter alia for the iron and steelmaking industry. This paragraph emphasises the cross-media effects of industrial production.

A concept similar to the one of BAT is the definition of the „state of the art technology“ in the BImSchG:

State of the art as used herein shall mean the state of development of advanced processes of facilities or modes of operation which is deemed to indicate the practical suitability of a particular technique for restricting emission levels. When determining the state of the art, special consideration shall be given to comparable processes, facilities or modes of operation that have been successfully proven in practical operation. (Article 3 paragraph 6 BImSchG)

In principle, it is stated in terms of emission limits to be attained and the choice of technology to comply with the achievable levels is left to the industry. The performance of BAT is a minimum level of pollution control in Germany. For existing plants, longer time frames for implementing BAT are given.

The necessary precautions against harmful effects on the environment are to be taken in particular by using control measures corresponding to the state of the art. Depending on the mass flow, some substances (eg. SO_x, NO_x, and particulates) have to be measured continuously. The BImSchG is specified by 21 ordinances and TA Luft.

BImSchV (Ordinance on small combustion plants):

The 1. BImSchV sets emission limit values for combustion installations for solid fuels, oil and gas and settles controls for the operation.

4. BImSchV (Ordinance on installations subject to licensing):

The 4. BImSchV (Ordinance on installations subject to licensing) lists the installations that are subject to licensing under the BImSchG. According to this ordinance, electric arc furnaces have to undergo a formal licensing procedure, regardless if they are new installations or material alternations to the location, nature or operation of existing installations.

13. BImSchV (Ordinance on large firing installations):

The 13. BImSchV (Ordinance on large firing installations) is applied in relation to the construction, nature, and operation of firing installations with an output of more than 50 megawatts, including auxiliary equipment. This Ordinance basically sets limits for dust emissions, the emission of nitrogen oxides (NO_x), sulphur oxides (SO_x), and halogens compounds. The limits vary according to whether liquid or gas fuels are used or whether the emissions are caused by existing plants.

Technical Instructions on Air Quality (TA Luft):

The Technical Instructions on Air Quality (TA Luft) [2] have been set up as general administrative regulations in connection with the §48 BImSchG [cf. 18]. The TA Luft further specifies the requirements to be met by installations subject to licensing. Therefore, it prescribes limit values for virtually all air pollutants as well as structural and operational requirements designed to limit diffuse emissions. Existing melting plants had to comply with the TA Luft (as at 1986) requirements by 1994. For the new federal states, the requirements had to be met before 1996, in special cases by 1999. Table 8-4 shows the limits for main emission control requirements or, if there exist specific regulations for EAF plants, the corresponding more specific requirements laid down in the TA Luft, which direct at the avoidance and minimisation of air pollution.

Table 7-4: Emission control requirements laid down in the TA Luft

Emitted substance (TA Luft section)	**Class**	**Substances**		**Mass flow threshold [g/h]**	**Concentration limit [mg/m³]**
Dust containing waste gases (3.3.3.3.1 a))		dust containing waste gases are to be captured as far as possible and to be lead to a gas cleaning system, if this is necessary to comply with further requirements.			
Total dust for EAF plants (3.3.3.3.1 b))					20
Inorganic dust-like	I	(eg. Cd, Hg, Tl)	sum of substances	1	0.2
particles	II	(eg. As, Co, Ni, Te, Se)	- " -	5	1
(3.1.4)	III	(eg. Sb, Pb, Cr, F, Cu, Mn, Pt, Pd, Rn, V, Sn)	- " -	25	5
	I+II		- " -		1
	I+III, II+III		- " -		5
Vaporous or	I	(eg. AsH_3)	per substances	> 10	1
gaseous inorganic	II	(eg. HF, Cl_2, H_2S)	- " -	> 50	5
substances	III	(eg. Cl-compounds as HCl)	- " -	> 300	30
(3.1.6)	IV	(eg. SO_2, NO + NO_2 as NO)	- " -	> 5.000	500
Organic substances	I	(eg. Chlormethane)	Classification	> 100	20
(3.1.7)	II	(eg. Chlorbenzene)	according to	> 2.000	100
	III	(eg. Alkylalcohols)	Annex E of TA Luft	> 3.000	150
Carcinogens	I	(eg. asbestos, benzo(a)pyren)		≥ 0.5	0.1
	II	(eg. arsenic trioxide, dimethylsulfate)		≥ 5	1
	III	(eg. Acrylonitrite, benzene)		≥ 25	5
Carbon monoxide (3.3.3.3.1)		shall be utilised or burned as far as possible.			

Class I substances are most toxic while Class III are least harmful. The emission limit values contained in the TA Luft represent BAT of technical measures for reducing emissions (dating from 1986). These quality values were developed referring to scientific findings and research taking into account toxicological, bioaccumulative and epidemiological aspects.

Since the TA Luft stems from 1986, the local authorities demand stricter emission limit values. Therefore, the state Baden-Württemberg defined new limits [91]. This procedure, however, is being criticised [8].

Technical Instruction on Noise Abatement:

The Technical Instruction on Noise Abatement (TA Lärm) [5] sets the limits for noise emission of the operation of a facility permitted in various areas. The construction, operation or altering of a facility is granted only if the emission limits allowed for a specific area are not exceeded and if state-of-the-art noise protection measures are employed.

Model administrative regulation by LAI:

The LAI issued under the overall control of the Ministerium für Umwelt, Raumordnung und Landwirtschaft des Landes Nordrhein-Westfalen (MURL) a model administrative regulation [62] for residues resulting from installations subject to § 5 Abs. 1 Nr. 3 BImSchG. Within this regulation technical measures are listed for the prevention and control of solid residues of electric steelmaking plants. Table 8-5 gives an overview of the proposed measures.

Table 7-5: Technical measures of the model administrative regulation for the prevention and control of residues resulting from EAF plants according to LAI

Prevention			
Technical measure	a) Prerequisites for prevention b) Area of application	Reasonableness	Prevention rate
Residue: Dust of waste gas cleaning system		*Origin: Waste gas cleaning sytem*	
Input for electric steelmaking	a) Briquetting b) Recycling to EAF	evaluate reasonableness on a plant by plant basis	
Residue: Ladle slag		*Origin: Ladle metallurgy installation*	
Input for electric steelmaking	a) b) Treatment by crushing	reasonable	
Residue: Steel skulls			
Input for electric steelmaking	a) Treatment by crushing b) as iron containing material	reasonable	
Residue: Waste water			
Closed loop system	a) according installation of systems b)	reasonable	

Table 8-5: Technical measures of the model administrative regulation for the prevention and control of residues resulting from EAF plants according to LAI (2)

Utilization			
Technical measure	a) Prerequisites for utilization b) Area of application	Reasonableness	Harmlessness
Residue: Dust of waste gas cleaning system		*Origin: Waste gas cleaning system*	
Input for non-ferrous metal production	a) Enrichment by Waelz-process b) Waelz-oxide as input for IS-furnace	reasonable	harmless
Input for electric steelmaking	a) Remelting in plasma furnace b) Production of chromium-nickel alloy	evaluate reasonableness on a plant by plant basis	harmless
Input for pig iron production, steel production	a) Pelletizing, treatment by Inmetco-process b) Use in blast furnace, BOF	evaluate reasonableness on a plant by plant basis	harmless
Sludges of waste gas cleaning:	*not considered*		
EAF/Ladle slag		*Origin: EAF, Ladle furnace*	
Use in road and soil construction	a) Keeping of according requirements b) Eg. covering-, binder-, and base course	reasonable	evaluate harmlessness on a plant by plant basis
Addition to construction material	a) Keeping of according requirements b) For construction purposes	reasonable	principally harmless
Addition to fertilizer	a) Keeping of according requirements b) Agriculture and forestry	reasonable	harmless (if requirements are met)
Refractory breaks		*Origin: EAF, Ladle*	
Input for sinter plant, pig iron production	a) Sorted provision of refractory breaks b) Input for sinter plant and blast furnace	evaluate reasonableness on a plant by plant basis	harmless
Use in road and soil construction	a) Keeping of according requirements b) Eg. covering-, binder-, and base course	principally reasonable	evaluate harmlessness on a plant by plant basis
Input for refractory material industry	a) Sorted provision of material, separation of iron b) Source material for refractory material	reasonable	harmless

7.1.3.2 German regulations concerning the water quality

The legal instrument for water management, analogous to the BImschG for air pollution control is the Federal Water Act (Wasserhaushaltsgesetz WHG) [37]. The WHG is in force for waste water generated by various industrial processes, including the iron and steel industry. The use of surface, coastal, and ground waters requires the approval of the competent authority. Water discharges are mainly dealt with within art. 7(a) WHG, which allows to lay down specific discharge rules for water polluting sources. The water protection legislation is implemented by the Ordinance on the Industrial Sources of Water and by general administrative regulations concerning minimum requirements to be met by discharges, irrespective of the quality of the receiving medium. Each of the 16 Bundesländer has its own legislation which repeats and adds to the Federal Law.

The WHG is complemented by the discharge levy act (Abwasserabgabengesetz: AbwAG) [35]. The tariffs are related to the mass and possible hazard of the discharged waste water according to Table 8-6. For discharge of sewage, that exceeds the mentioned threshold values for concentrations or annual freights, the discharging party has to pay a fee related to the given units of measurement.

Table 7-6: Thresholds according to the discharge levy act

Hazardous Substances	Units of measurement (relating to a unit of hazard)	Threshold values	
		Concentrations	Annual freights
Oxydizable substances (given as COD)	50 kg Oxygen	20 mg/l	250 kg
Phosphor	3 kg	0.1 mg/l	15 kg
Nitrogen	25 kg	5 mg/l	125 kg
Organic Halogen compounds as AOX	2 kg Halogen, calculated as Cl	100 µg/l	10 kg
Mercury & compounds.	20 g	1 µg/l	0.1 kg
Cadmium & compounds	100 g	5 µg/l	0.5 kg
Chromium & compounds	500 g	50 µg/l	2.5 kg
Nickel & compounds	500 g	50 µg/l	2.5 kg
Lead & compounds	500 g	50 µg/l	2.5 kg
Copper & compounds	1000 g	100 µg/l	5 kg
Fish toxicity	3,000 m^3 discharges divided by G_F	G_F =2 (dilution factor for non-lethality for fishes of the discharge)	

Minimum requirements are placed on sewage lines from certain legally fixed sources. Such requirements are in particular laid down in the Frame Regulation on Administration of Discharges (Rahmen-Abwasserverwaltungsvorschrift, Rahmen-Abwasser VwV). The iron and steel production is dealt with in Annex 24 A of that regulation [1]. According to this Annex, generally, waste water obtained within the following processes may not be discharged: Sintering plant, pig iron desulphurisation, and crude steel production, with the exception of gas cooling and secondary metallurgy. In section 2.1.2 of that Annex further requirements are stated to minimise the level of harmful substances in the waste water. Table 8-7 provides important restrictions established by the Rahmen-Abwasser VwV, especially for crude steel production including secondary metallurgy. Excluded from this regulation is waste water from cooling systems for the indirect cooling of industrial processes and process water treatment. Waste water obtained by these activities is subject to the provisions laid down in Annex 31, Rahmen-Abwasser VwV. Table 8-8 gives relevant requirements to discharges of this Annex 31 [1]. If the stated values are not observed, approval for the discharge of waste water will be denied.

Table 7-7: Requirements to discharges from the iron and steel production (Annex 24, Rahmen-Abwasser VwV), last altered the 15th of April 1996

Hazardous Substances	Only gas cooling and secondary metallurgy of crude steelmaking
Chemical Oxygen Demand COD	50 mg/l
Iron	5 mg/l
Hydrocarbons	-
Nitrogen from nitrite (NO_2-N)	-
Total phosphorus	-
Fluoride	-
Lead	0.5 mg/l
Chromium, total	0.5 mg/l
Copper	-
Nickel	0.5 mg/l
Zinc	2 mg/l
Tin	-
Fish toxicity as thinning factor	2

Among most others, a federal state that constituted regulations for indirect discharges is Baden-Württemberg [80]. The Directive is applicable for all industrial plants in Baden-Württemberg, as long as no federal regulations are provided. However, as most plants in the iron and steel industry are directly discharging waste water and therefore have to comply with the corresponding regulations for direct discharge, the Directives on Indirect Discharges are of minor interest.

Table 7-8: Requirements to discharges from cooling systems of industrial processes (Annex 31, Rahmen-Abwasser VwV), last altered the 15th of April 1996

Hazardous Substances	Minimal Requirements
Chemical Oxygen Demand COD	40 mg/l
Phosphor compounds, given as P	3 mg/l
Zinc	4 mg/l
AOX	0.15 mg/l
Available residual chlorine	0.3 mg/l
Chromium compounds	must not be contained
Mercury compounds	must not be contained
Nitrite	must not be contained
Metal organic Compounds (Metal-Carbon-Compound)	must not be contained

7.1.3.3 German regulations concerning the waste management and disposal of hazardous materials

A working group of the federal states on waste (Länderarbeitsgemeinschaft Abfall, LAGA) issued a categorisation of waste types, comprising 589 types of waste, of which 333 have priority for control [61] (*LAGA-Abfallartenkatalog*). This catalogue is valid till 12/31/1998 and will be replaced by the European waste catalogue (EWC) in the following [63]. To facilitate the change from the LAGA catalogue to the EWC, the German *LAGA* worked out an interim catalogue (*LAGA-Umsteigekatalog*) [60]. Table 8-9 summarises the classification of relevant substances generated within the iron and steelmaking industry (cf. [61, 60]).

Table 7-9: LAGA/EWC numbers for wastes resulting from the iron and steelmaking industry

Type of Waste	LAGA Waste Key	EWC Waste Key / remarks
Blast furnace slag	312 19	1002 01 Waste generated in BF slag preparation 1002 02 Untreated BF slag
Blast furnace gas dust	312 15	1002 03
Blast furnace gas sludge	316 19	1002 04
Iron containing dust without hazardous substances (eg. From casting bay dedusting, secondary dedusting, ...)	351 01	1002 03
Plant residues (runner breaks, ladle breaks, converter breaks, refractory breaks, etc.)	311 02 311 03; 311 06 311 08	1002 06 Refractory breaks
Converter slag, steelworks slag	312 20	1002 01 Waste generated in slag preparation 1002 02 Untreated slag
Coarse converter dust and sludge	312 17; 316 14	1002 03 / 1002 05
Fine converter dust and sludge	312 17; 316 14	1002 03 / 1002 05
EAF slag	312 18	1002 01 Waste generated in EAF slag preparation 1002 02 Untreated EAF slag
EAF dust	312 17	1002 03

7.2 Additional information on inputs: Energy and lining

Energy (electrical):

Making steel out of scrap requires a considerable amount of energy. The energy needed to melt and to refine the scrap is supplied in the form of heat, mainly produced by an electric arc generated by electrical energy. The minimum temperature needed to melt ordinary scrap is about 1,400-1,520 °C. Actual temperatures at the hottest spots in the furnace increase up to 3,500 °C, putting an immense strain on the inside walls of the furnace. Liquid steel, molten in electric furnaces, contains an enthalpy of 397-405 kWh/t. This heat and also heat losses by radiation, cooling, waste gas, and slag have to be provided by different energy sources. Figure 8-1 provides two Sankey-diagrams depicting the energy origin and use for two modern electric arc furnaces.

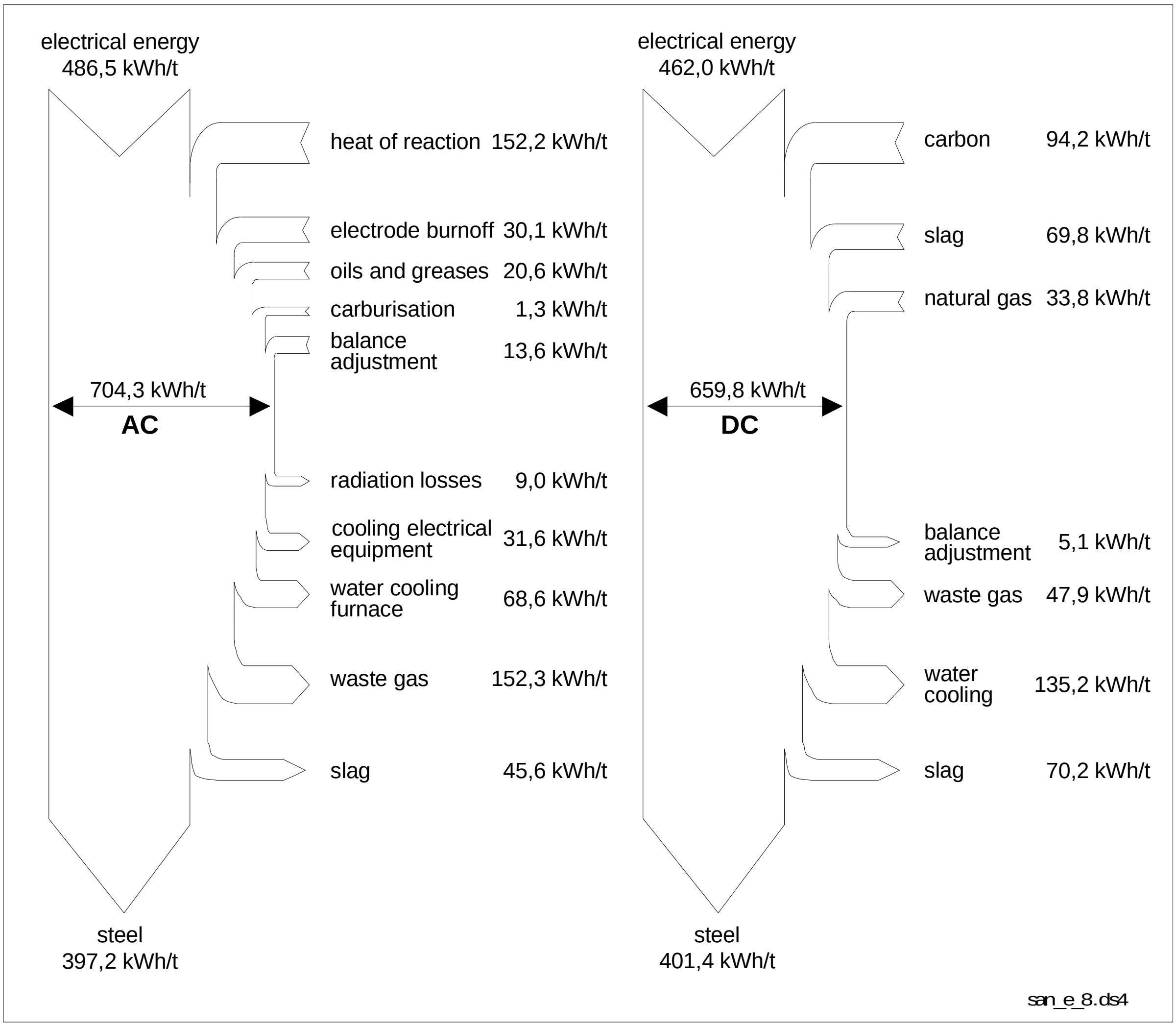

Figure 7-1: Sankey-diagrams (energy flows) for an AC and a DC furnace

Source: [57]

During recent decades the specific electrical energy input has been reduced from 630 kWh/t (1965) to 410 kWh/t (1990) and lower [28]. In contrast, the specific power supply has increased steadily. Examples of the specific power supply for three recently installed furnaces are 1 MVA/t (ARES Esch-Schifflange, Luxembourg) [99], 1.4 MVA/t (PSAG, Peine) [32], and 1 MVA/t (GMH, Georgsmarienhütte) [72]. Melting times and tap-to-tap times depend on the type of EAF in use. Current furnaces usually achieve melting periods of about 40 to 60 minutes and tap-to-tap times of about 1 hour [86]. Most modern furnaces with an ultra high power (UHP) supply achieve tap-to-tap times of about 50 minutes, eg. Arbed in Luxembourg [99] and PSAG in Peine [32].

Lining:

Besides the heat, also chemical and physical impacts impose high stress on the metallurgical vessels. To protect the furnace and the vessels for secondary metallurgy processes from wearing out too fast, the interior of the vessels is lined with refractory materials. These materials are characterised by their resistance to high temperatures (fusion point above

1,500 °C: refractory bricks, fusion point above 1,800 °C: highly-refractory bricks), resistance to thermal shock, robustness against chemical and physical attack by inputs, fluxes, heat, and liquid slags, as well as volume stability, thermal conductivity, and electrical conductivity [50]. Mechanical stress arises by charging operations, agitation of heat and slag, blowing in of gases and solids, tilting of furnace, and tenses caused by the laying of bricks. Thermal strain is caused by heating and exothermic reactions, infiltration of metals, discontinuous modes of operations, tilting of the furnace, and blowing in of gases. Chemical attack arises by hydration, the impact of several partial oxygen pressures, the reduction of the heat, including infiltration, and chemical impacts of slag components [33]. Typical refractory materials are products on a dolomite base ($CaMg(CO_3)_2$ compound), on a magnesite base, on a fire clay-base (main compounds are alumina (Al_2O_3), silica (SiO_2), and impurities), refractory specials, or insulating materials. Despite sophisticated lining techniques, i.e. employing various materials for the differently worn zones of the furnace, wear and tear caused by mechanical stress and chemical attack is inevitable. After a certain number of melts the furnace has to be lined again. The total refractory material consumption generally consists of two components. One part arises by the breaking out of contaminated refractory material, another part results from continuous wear and tear and is combined with slag or dust. The total average consumption of refractory material (furnace and secondary metallurgy vessels) depends significantly on the type of steel produced. It can be assumed to be within the following limits [49]:

Carbon steels:	approximately 12 kg/t,
High grade steels (alloyed and stainless steels):	approximately 22-32 kg/t.

The refractory consumption in the furnace itself amounts to 8.1 kg refractory breaks per ton of steel produced on average. It varies between a minimum of 1.9 kg/t steel and a maximum of 25.1 kg/t steel and also depends on the produced steel quality, furthermore on the tap-to-tap time and the heat temperature at tapping [49]. A possible prerequisite for the production process is the sorting of scrap. This step may create significant levels of noise of up to 106 dB(A).

Further inputs:

Emissions into the air may arise during the delivery, storage (hoppers), and handling (transport, conveyor belts) of other inputs like fluxes or silica. Statements in detail on these releases have not been available.

7.3 Generation and characteristics of EAF dust

Principally, there are three different mechanisms of dust generation in an EAF. The first one is the generation of dust particles by mechanical means. This mechanism is based on the abrasion of charged materials, for example lime. Fine particles of input materials are drawn away by the off gas stream. The second mechanism is dust generation by the carrying away of slag and steel particles with the exhaust gas. Particles are formed as small slag or steel droplets in two different ways. One way is the formation of droplets by mechanical impact of gas flows (for example oxygen lancing) on melt or slag, another way is the bursting of steel drops caused by chemical reactions. The third mechanism of dust generation is the evaporation of elements (like zinc and lead) and compounds (eg. chlorides). Table 8-10 gives an overview of dust formation mechanisms for selected elements and compounds.

Table 7-10: Mechanisms of dust formation

	Mechanical dust formation	Formation of droplets	Evaporation
Fe, Fe_2O_3...	if ore is charged	melt and slag	
SiO_2	if silica is used	slag	
CaO	with lime additions	slag	
Zn, Pb ...			after reduction of oxides
KCl, NaCl ...			physical evaporation

The majority of particulate emissions from EAF steelmaking is generated during melting and oxygen lancing, or injection. The particulates are composed of iron oxides, lime and various oxidised metal and non-metal elements. EAF dust is a mixture of very fine particles with an average size below 5 μm. EAF dust generated in carbon steel production tends to be rich in zinc and lead, whereas dust from alloy steelmaking contains significant amounts of alloying elements like chromium, and nickel.

EAF dust generated in carbon steel and stainless steel production processes may be classified as a hazardous waste for the existence of water leachable elements like heavy metals zinc, lead, cadmium. Eg., this has been done by the environmental protection agency (EPA) of the United states. A list of typical analysis of EAF dusts is given in Table 8-11.

Table 7-11: Typical chemical analysis of EAF dusts [wt.-%]

Source of information	Zn	Pb	$Fe_{tot.}$	CaO	$Cr_{tot.}$	Ni	Mo
Carbon steel production							
by Weiss [23]	30	4.5	22	n.a.	n.a.	n.a.	n.a.
by EPRI [24]	19.0	2,1	28.5	n.a.	0.39	n.a.	n.a.
by Hartwell [41]	5-35	1-5	35-55	2-14	n.a.	n.a.	n.a.
by Frada [30]	23.4	5,4	22	10.7	n.a	n.a	n.a
by Kola [56]	15-35	1-8	20 - 30	5-12	0.1-0.4	0.05 – 0.25	< 0.1
High Grade steel production							
by Werner [99]	1.9	1.9	29 (Fe_2O_3)	0.7	13,7	3,75	n.a.
by EPRI [25]	1.0	1.1	31.7	3.1	10.2	n.a.	n.a.
by Kola [56] *)	1-7	0.2 – 1.5	25-45	3-10	10-15	3-7	1-2
by Etienne [26]	2-5	0.3-0.7	30-40	10-25	16-22	2-4	0-4
**)	0.38	0.1	59.7	2 (Ca)	12.4	3.9	n.a.

*) analysis of EAF dust from stainless steel production

**) information by steel industry

7.4 Distribution list and received comments

A preliminary draft version of this document has been distributed to several German and international institutions in order to stimulate discussions, to enable an information exchange, and to receive comments. Among the contacts within these institutions have been the following persons:

Mr. de Jonge, Ministry of Housing, The Hague, The Netherlands;

Mr. Nyström, Swedish EPA, Industry and Ecocycles Department, Stockholm, Sweden;

Mr. Weber, Ministry of Environment, Luxembourg, Luxembourg;

Mr. Göller, Ministry of Economic Affairs, Vienna, Austria;

Mrs. Karhu, Finnish Environment Agency, Helsinki, Finland;

Mr. Dyhr, Danish Environment Agency, Copenhagen, Denmark;

Dr. Weigel, Senat für Frauen, Gesundheit, Jugend, Soziales und Umweltschutz, Bremen;

Mr. Theobald, Verein Deutscher Eisenhüttenleute (VDEh), Düsseldorf.

We would like to thank all of the involved institutions, in particular the Ministry of Housing of The Netherlands, the VDEh in Germany, and the representative of the Senat in Bremen for their prompt and constructive responses [67, 84, 92]. The received comments have been checked and topics that seemed to be appropriate have been taken into account. We also have been glad about getting some good reviews.

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