Working Paper

Emission Reduction Through Restructuring of the Non-Ferrous Metal Industry in the Ruhr Area

A Historical Record

Simone Schucht

WP-96-36
April 1996

IIASA International Institute for Applied Systems Analysis • A-2361 Laxenburg • Austria
Telephone: +43 2236 807 • Telefax: +43 2236 71313 • E-Mail: info@iiasa.ac.at

Emission Reduction Through Restructuring of the Non-Ferrous Metal Industry in the Ruhr Area

A Historical Record

*Simone Schucht**

WP-96-36
April 1996

*Forschungsstelle für Umweltpolitik (FFU)
Fachbereich Politische Wissenschaft
Freie Universität Berlin
Schwendenerstrasse 53
D-14195 Berlin

IIASA International Institute for Applied Systems Analysis • A-2361 Laxenburg • Austria
Telephone: +43 2236 807 • Telefax: +43 2236 71313 • E-Mail: info@iiasa.ac.at

Preface

This paper presents a contribution to the `Regional Material Balance Approaches to Long-Term Environmental Policy Planning' project (IND project). The policy part of this project - the Ruhr/Katowice Policy Comparison - aims at providing better understanding of policy options for cleaning up the Black Triangle [cf. Blazejczak 1995]. The comparison focusses on the Ruhr Area and on the Katowice voivodship which have both been identified as heavy metal pollution hot spots. The Ruhr/Katowice Policy Comparison comprises a historical analysis of the Ruhr Area. It draws heavily on the evidence collected in IIASA's previous Rhine Basin study and investigates previous policies to reduce heavy metal pollution in this area [cf. Stigliani et al. 1993; Stigliani/Anderberg 1992].

This paper describes those determinants of intrasectoral change within the sector of non-ferrous metal production in the Ruhr Area which have contributed to the reduction of atmospheric heavy metal emissions since the mid-sixties. The driving forces behind these intrasectoral changes are also investigated. This investigation is based on earlier research by de Bruyn and Schucht [1996] which showed that intrasectoral change has been the most important factor in the reduction of atmospheric heavy metal emissions from industrial point sources.

TABLE OF CONTENTS

List of Figures and Tables

Abbreviations

ABMS	American Bureau of Metal Statistics
Cd	Cadmium
e.g.	for example
i.e.	that is
IHK	Industrie- und Handelskammer
IIASA	International Institute for Applied Systems Analysis
Ld	Lead
LDS	Landesamt für Datenverarbeitung und Statistik Nordrhein-Westfalen
NF-Metals	non-ferrous metals
NRW	Northrhine-Westfalia
SO_2	sulphur dioxide
StaBu	Statistisches Bundesamt
StaLa	Statistisches Landesamt Nordrhein-Westfalen
t	tonnes (metric)
TA	Technische Anleitung (`technical direction')

Abstract

This working paper describes those determinants of intrasectoral change within the sector of non-ferrous metal production in the Ruhr Area, Northrhine-Westfalia, which contributed to the reduction of atmospheric heavy metal emissions since the mid-sixties, as well as the driving forces behind these intrasectoral changes. It constitutes part of the Rhine/Black Triangle Policy Comparison Study at IIASA.

Intrasectoral changes pertaining to the emission of atmospheric heavy metals are shown to have consisted, in the first place, of process changes whose main characteristic was increased processing of production residues, i.e. a closing of economic (material) cycles, thus increasing recycling and decreasing waste. The second most important development was the application of gradually improved off-gas collection and cleaning technologies (end-of-pipe technologies).

Closures of old plants also have contributed to the decrease in heavy metal emissions. Although capacities were increased during the period of the investigation (1955 to 1988), these capacity increases were brought about with modernized technologies, which are less emission intensive than those used in the older plants.

Three major factors were the driving forces behind the intrasectoral change:

- developments in legal requirements (air pollution control),
- economic motivations of the enterprises and
- financial support from public institutions.

An open question is whether various residues resulting from the more modern processing technologies are, from an environmental point of view, more hazardous than heavy metal emissions.

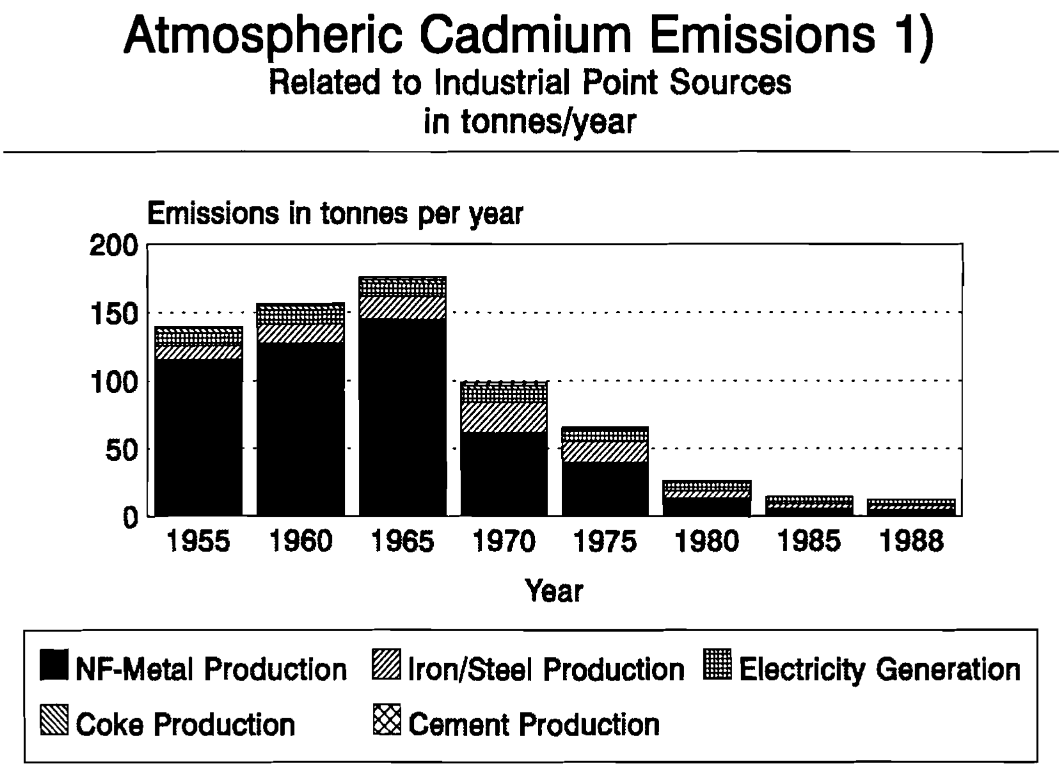
1. Introduction

The aim of this paper is an investigation of the restructuring process relevant to airborne heavy metal emissions of the non-ferrous metal industry in the Ruhr Area, i.e. the production of the non-ferrous metals copper, zinc and lead. These belong to the major industrial point sources of atmospheric heavy metal emissions of cadmium, lead and zinc.

1.1. Study Background

Figures 1.1. to 1.3. show atmospheric emissions of cadmium, lead and zinc from industrial point sources in the Rhine Basin area of Northrhine-Westfalia between 1955 and 1988[1].

Figure 1.1.

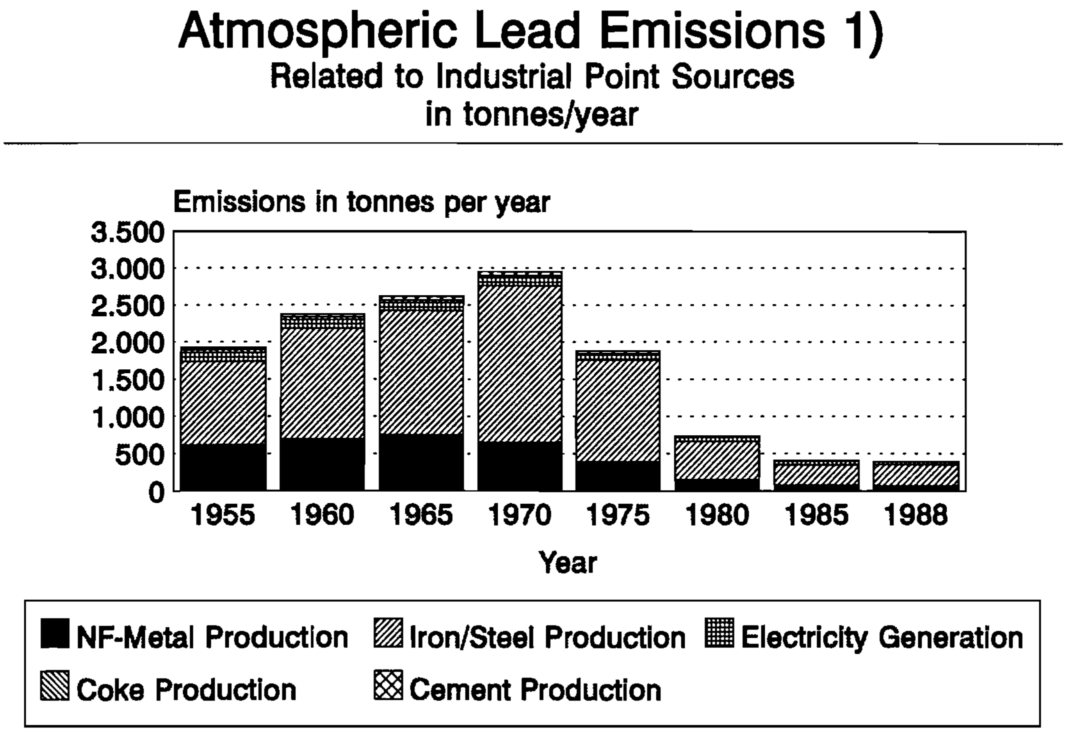


1) Rhine Basin part of Northrhine-Westfalia.

Source: IIASA.

[1] The emission data are average values for 5-year periods. For the sake of simplicity time periods are denoted by their mid-value, e.g. 1955 denotes the period from 1953 to 1957.

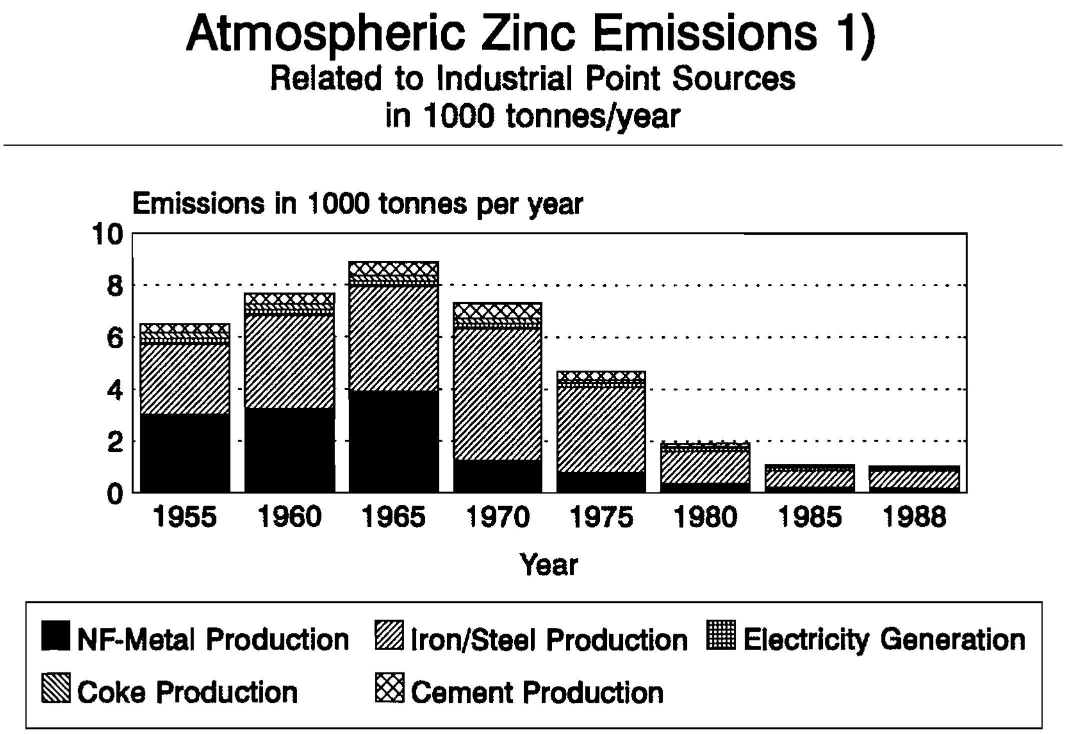
Figure 1.2.



1) Rhine Basin part of Northrhine-Westfalia.

Source: IIASA.

Figure 1.3.



1) Rhine Basin part of Northrhine-Westfalia.

Source: IIASA.

Heavy metal emissions decreased considerably between 1955 and 1988, with the major decreases occuring during a relatively short period of time from 1965 to 1980. With respect to cadmium emissions we find, that the non-ferrous metal industry was most important for both, the amount of industrial heavy metal emissions and their decline since the mid 60's. With respect to lead and zinc emissions the non-ferrous metal industry was - next to iron and steel production - of second highest importance.

1.2. Research Aims

These findings raise the question of which industrial changes led to the distinct decline in the emission of cadmium, lead and zinc since the mid sixties. In earlier research by de Bruyn and Schucht [1996] it was shown that intrasectoral changes - i.e. changes occuring within a specific economic sector[2] - have been most important for the reduction of atmospheric heavy metal emissions caused by industrial point sources. The focus of the present study will, therefore, be on an investigation of the various determinants of intrasectoral change within the non-ferrous metal sector, as well as on the driving forces behind these changes.

The following table gives a classification of the determinants of *intrasectoral change*.

Table 1.1.

Classification of Determinants of Intrasectoral Change [De Bruyn/Schucht 1996]:

- end-of-pipe technologies,
- substitution of inputs (including the use of recycled inputs),
- process-related technological changes:
    - process modifications,
    - new processes,
    - good housekeeping by organizational-technical measures or minor technological changes (e.g. covers over conveyor belts),
- product related technological changes:
    - changes in the spectrum of products produced in a specific industry (intrasectoral structural shifts) and
    - a reduction of the physical intensity of production (dematerialization).

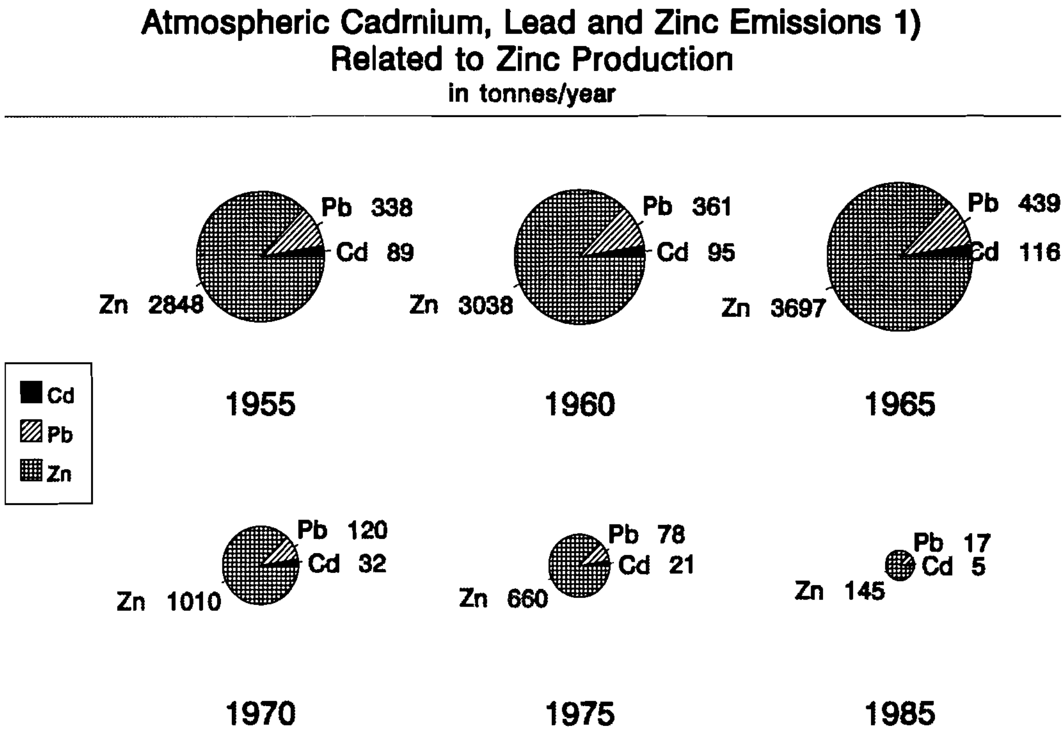
---

[2] Intrasectoral change includes a) intrasectoral structural shifts (increase or decrease of shares of specific productions within an economic sector), b) the application of different technologies (including process and product related technological shifts and the application of end-of-pipe technologies), and c) a substitution of inputs [Schucht 1993; De Bruyn/Schucht 1996]. Intrasectoral change can be classified as shown below (see table 1.1.).

Driving Forces for intrasectoral change include developments in the legal framework with respect to pollution control and technological requirements as set by federal or local authorities, increasing public concern about pollution, and economic developments (e.g. changes in the demand for products or in international competition).

For the investigation of individual plants it is also important to know how the emissions of cadmium, lead and zinc caused by the production of zinc, lead and copper developed. Figures 1.4. to 1.6. show these developments for the Rhine Basin part of Northrhine-Westfalia between 1955 and 1988.

Figure 1.4.

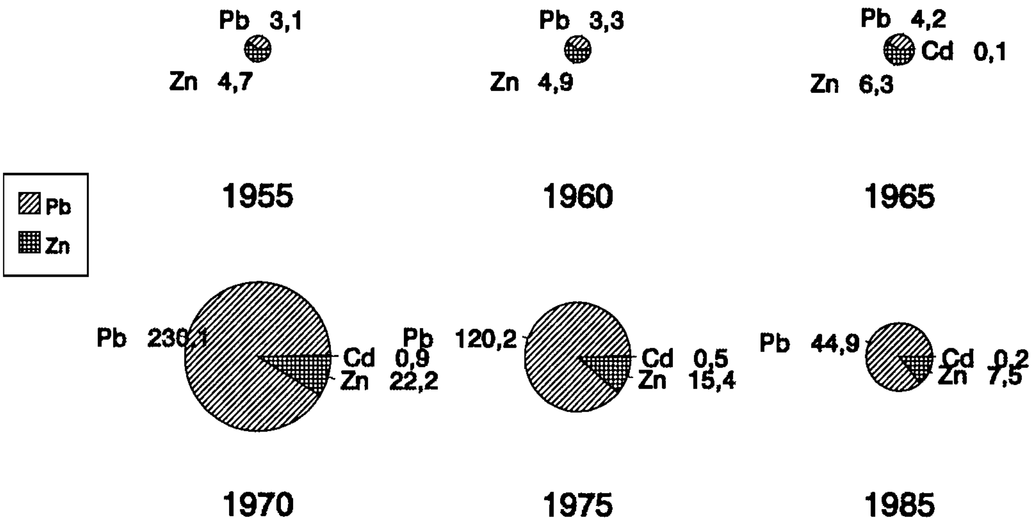


1) Emission data for the Rhine Basin part of Northrhine-Westfalia
Source: IIASA.

Figure 1.5.

Atmospheric Cadmium, Lead and Zinc Emissions 1) Related to Lead Production

in tonnes/year

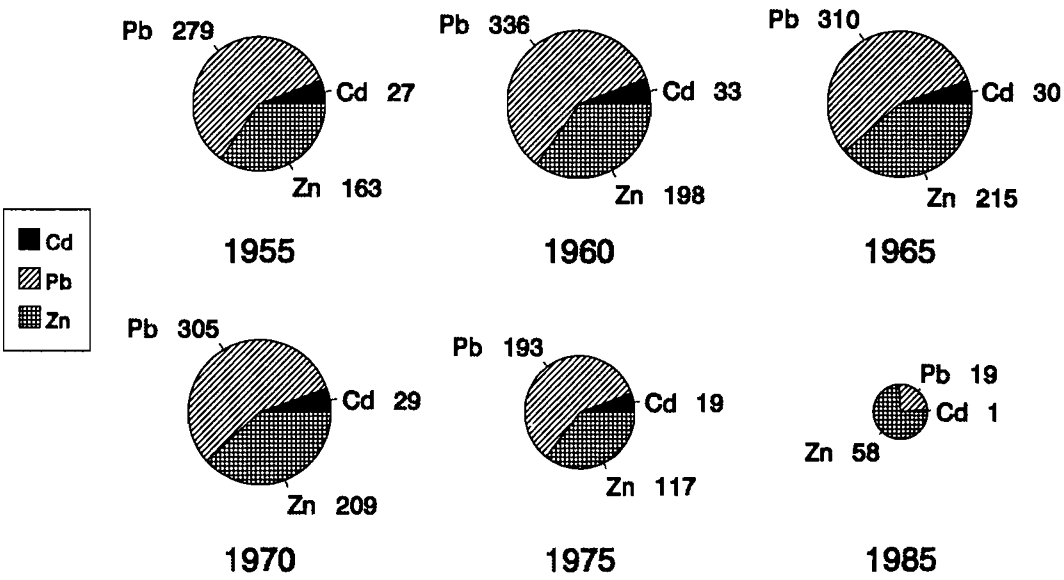


1) Emission data for the Rhine Basin part of Northrhine-Westfalia
Source: IIASA.

Figure 1.6.

Atmospheric Cadmium, Lead and Zinc Emissions 1) Related to Copper Production

in tonnes/year



1) Emission data for the Rhine Basin part of Northrhine-Westfalia
Source: IIASA.

These figures show that zinc production was the major determinant for heavy metal emissions. For *zinc emissions* the production of zinc was the major factor and the copper production a secondary factor. But while zinc emissions due to zinc and copper production declined from the mid sixties, zinc emissions due to lead production increased until around 1970. The main reductions in emissions, however, were achieved in the zinc production.

Regarding *lead emissions* zinc production was the major factor until the mid sixties, whilst copper production was most important in the time period 1970 to 1975. Only after 1975 was lead production most important. Lead emissions resulting from copper production have declined since the early 60's, from zinc production since the mid 60's and from lead production since the early 70's. However the most significant decline comes from zinc production.

For *cadmium emissions*, zinc production was also the major factor throughout the entire period investigated. While copper production also contributed considerably to the emission of cadmium, lead production was of only minor importance. Cadmium emissions resulting from copper production have declined since the early 60's, from zinc production since the mid 60's and from lead production since the early 70's. The most significant reductions were again achieved with zinc production.

1.3. Method of Investigation

In a first part of this study a brief overview of the significance of the non-ferrous metal industry within West-German industry as a whole and its specific situation with respect to raw materials, costs and prices is given. The producer price development and the development in legal framework (air pollution control), belonging to the driving forces of the industry's development, are also investigated.

In a second part, information on the economic development of the non-ferrous metal industry in Northrhine-Westfalia is presented and intrasectoral changes in this sector are investigated. Technological and organizational-technical changes are investigated at the level of individual plants.

In conclusion, consideration is given to the questions of whether a connection of environmental and economic requirements has been met by the restructuring of the non-ferrous metal industry in the Ruhr Area (Northrhine-Westfalia), and what the important factors behind this restructuring were.

1.4. Hypotheses

Based on the research aims to determine a) the industrial changes that have led to the distinct decline in the emission of cadmium, lead and zinc since the mid sixties and b) the driving forces behind these changes, this investigation follows three hypotheses whose validity is assessed throughout this study.

Hypotheses on Intrasectoral Change

1) Intrasectoral change relevant to the emission of heavy metals consisted primarily of process changes. Its main characteristic was the increased processing of production residues, thereby closing material cycles and, thus, combining the ecological clean-up with a higher efficiency.

2) A second important development was the application of gradually improved end-of-pipe technologies for the collection of waste gases and dust from furnaces. The costs for these technologies per unit of pollutants abated decreased significantly over the period of the investigation.

Hypothesis on Driving Forces Behind Intrasectoral Change

3) Three components were important as driving forces behind these intrasectoral changes:

- the enterprises' economic motivations,
- legal requirements and
- financial support given by public authorities or the government.

2. Economic Background for the Non-Ferrous Metal Industry in West-Germany

In this chapter a brief overview of the significance of non-ferrous metals within industry in West-Germany as a whole is presented. Its specific situation with respect to raw materials, costs and prices is given. The development of the producer price, an important driving force behind industrial change, is also investigated.

Together with chapter 3., which describes the development of the legal framework with respect to air pollution control, this chapter serves as background to the investigation of intrasectoral changes which is presented at the level of individual plants in chapter 4.

2.1. Significance of Non-Ferrous Metals within Industry as a Whole

In terms of factors such as employment and turnover, non-ferrous metals have always played only a minor role in West-German industry. In 1976 the share of the non-ferrous metal industry[3] with respect to employment and turnover was 1.6% and 2.1%[4] respectively. The greatest part of the turnover within the non-ferrous metal industry was achieved by the metal-refineries and re-melting plants (43%). With respect to employment only 14% fell to these plants [Wettig 1980]. Owing to concentration and rationalization processes, productivity (measured as turnover per employee) was increased by a factor of 3.5 between 1956 and 1976.

Despite its minor importance in terms of total employment and turnover the non-ferrous metal production has strategic importance. It is a base industry for the economy. Economically important industries such as electrical engineering, mechanical engineering, communication technology, electrotechnical industry and road and rail vehicle industries depend on non-ferrous metals as inputs for their production [Boesler/Breuer 1989; Gebhardt/Knörndel 1977; Krol/Steil 1987]. Its importance can, therefore, be mainly seen as securing the supply of resources to downstream industries.

The non-ferrous metal industry is also economically important as buyer of products from several sectors such as electricity generation, mechanical engineering, construction/building, steel-girder construction, trade and metals, and is therefore also important for employment in these sectors [Boesler/Breuer 1989].

2.2. Raw Materials

Owing to a limited mineral resource basis in West-Germany only small quantities of lead and zinc are extracted from domestic reserves. The non-ferrous metal production capacity therefore relies on imported raw materials [OECD 1994].

---

[3] The figures given for employment, turnover and productivity comprise those for ore mines, refineries, re-melting plants, foundries and production of semi-finished products.

[4] Compared to 1956 the share of the non-ferrous metal industry within industry as a whole in 1976 with respect to turnover had declined by 0,4 percentage points.

Table 2.1.

Imported Raw Materials in Germany in 1000 tonnes		
	1973	1983
copper ore	514.8	496.3
lead ore	162.3	217.8
zinc ore	622.6	542.4

Source: Boesler/Breuer 1989.

Table 2.2.

Major Supplier Countries		
	Lead Ores	
1960	1973	1978
Peru	Ireland	Canada
Canada	Sweden	South Africa
Greece	Canada	Sweden
Bolivia	Marocco	Ireland
		Thailand
	Copper Ores	
1960	1973	1978
Cyprus	Papua-Newguinee	Papua-Newguinee
Chile	South Africa	Mexico
	Indonesia	Poland
	Cyprus	
	Norway	
	Zinc Ores	
1960	1973	1978
Sweden	Canada	Canada
Peru	Sweden	Sweden
Italy	Ireland	Ireland
		Greenland
		Australia

Sources: Boesler/Breuer 1989; Gebhardt/Knörndel 1977.

Because of the high share of imported raw materials, transport costs are crucial to the non-ferrous metal industry and to its competitive position [OECD 1994].

2.3. Primary and Secondary Production

Germany's limited ore resource basis and the high value of the metals make secondary non-ferrous metal production an attractive alternative to primary production. Additionally, secondary production requires less production steps [Gebhardt/Knörndel 1977] and, often, less energy than primary production.

Table 2.3.

Production of Primary and Secondary Metals in West-Germany in %					
	1960	1970	1975	1980 (1)	Early 90's
copper					
primary	57.4	51.1	58.9		
secondary	42.6	48.9	41.1	>30.0	49.0
lead					
primary	81.0	60.3	68.0		
secondary	19.0	39.7	32.0	45.0	49.0
zinc					
primary	70.0	75.3	78.9		
secondary	30.0	24.7	21.1	20.0	38.0

(1) Estimate [Saßmannshausen 1982].

Sources: Gebhardt/Knörndel 1977; Saßmannshausen 1982; Steil 1993.

The development of primary and secondary production is influenced by the respective prices of, and the availability of, raw materials. Secondary refineries can also adopt more easily to industrial fluctuation [Gebhardt/Knörndel 1977].

Table 2.3. shows that up until 1980 there was - except for lead production - no significant shift to secondary production. Increasing metal residues and scrap metal, increasing costs for the deposition of residues and environmental standards is now resulting in a continuous increase in secondary metal production (also processing of residues from other industrial sectors). The non-ferrous metal enterprises are investing heavily in changing their processes from primary refineries to either completely secondary production or to a production that can handle a high proportion of secondary materials [Steil 1993]. In the early 90's metal prices in Germany declined due to rising exports from eastern countries, declining demand owing to business cycle fluctuations and changes in the exchange rates. This reduced the incentives for secondary production. Stricter environmental standards are also expected to give German manufacturers disadvantages compared with those from other countries.

Information on the volume of production of the non-ferrous metal industry was not available from official statistical sources. Stigliani and Anderberg [1993] estimate the figures for the Rhine Basin area of Northrhine-Westfalia presented in table 2.4.

According to the data there was a gradual increase in copper production during the entire period of this investigation. Primary production showed an increasing trend until roughly 1975 and then gradually decreased. Secondary production on the other hand increased between 1955 and 1965 then, after a distinct decline during the period 1970 to 1975, increased considerably. Lead production shows an increasing trend, with, however, a distinct drop around 1975. There was a gradual increase of secondary lead production until about 1980.

Table 2.4.

Non-Ferrous Metal Production in Northrhine-Westfalia (1) in 1000 tonnes	1955	1960	1965	1970	1975	1980	1985	1988
Zinc Production	59	63	77	174	195	182	186	182
Lead Production								
primary	0	0	0	25	19	23	27	26
secondary	5	5	7	16	19	21	20	19
Copper Production								
primary	44	53	48	71	92	51	46	43
secondary	34	41	63	59	39	94	113	125

(1) Data for the Rhine Basin area of Northrhine-Westfalia.

Source: IIASA.

2.4. Costs

Energy Costs

The non-ferrous metal industry is highly electricity-intensive. Its share in the electricity consumption of total industry in 1980 was 6.1%. Its electricity consumption per employee in 1983 was more than three times higher than that of the iron and steel industry. A comparison of electricity costs and production value for 1980 shows that total electricity costs of the non-ferrous metal industry amounted to 7% of its production value, while these costs in the iron and steel and in the chemical industry amounted only to 2% and 3.8% respectively [Boesler/Breuer 1989]. The costs for electricity therefore represent a high share in the total production costs.

High electricity costs in Germany - combined with low zinc prices - are one of the main reasons why for example electrolytic zinc plants were not profitable at the end of the 70's and during the 80's, but operated at a loss [Boesler/Breuer 1989].

Costs of Environmental Protection

Important for emissions of heavy metals and dust are the standards set in the so called `technical directions air' (Technische Anleitung Luft), i.e. TA-Luft 1974, as well as in its amendments of 1983 and 1986. In the amendment of 1983 the standards set for *emissions* and relevant to the non-ferrous metal industry were not revised and did not mirror the best available technology at that time. Local authorities therefore frequently requested stricter standards before authorizing (new) plants [Boesler/Breuer 1989]. More important, however, are the standards set in the TA-Luft 1983 for *"immissions"*[5] of lead and

---

[5] The term "immission" comprises ambient air concentrations and depositions.

cadmium, which, indirectly, required emission standards much stricter than previous standards and made the cost of pollution control an important factor in the choice of the production location.

The share of investment for environmental protection in the total investment for non-ferrous metal refineries in Germany grew from about 12.8% in 1975 to about 34.7% in 1985[6] [StaBu FS19]. In the 80's the expenses of this environmental investment and of other investments could only be met by refineries belonging to huge enterprises, who were also involved in ore mining, and who accepted losses in the interest of maintaining the refineries as an element of their whole production [Boesler/Breuer 1989].

New standards set in the `technical direction air' of 1986 plus new standards for water pollution control were expected to cause additional costs of about DM 1 billion for the German non-ferrous metal industry. These costs were expected to result in even more rationalization and to put the industry under considerable pressure [Krol/Steil 1987].

2.5. Prices

Market prices for most non-ferrous metals are set on the metal stock exchange. This is important because nationally increasing costs such as electricity or investment in pollution control therefore cannot easily be passed on and compensated for by price increases [Boesler/Breuer 1989; Müller-Ohlsen 1981; Krol/Steil 1987]. While the prices for copper and lead are mainly determined by the London Metal Exchange, zinc prices are mainly determined by producers[7] [Gebhardt/Knörndel 1977].

Figures 2.1. to 2.3. show the development of zinc, lead and copper prices in the United States from 1955 to 1990. Due to varying exchange rates the absolute figures may differ for German producers, but the development can still be assumed to be comparable.

After a decline in the mid fifties *zinc prices* developed fairly steadily until the early 70's [Gebhardt/ Knörndel 1977]. After a sharp increase in 1973 and 1974 they steadily declined until 1978. The downwards trend continued until 1986[8]. Zinc prices then increased and, by the end of the 80's, had almost reached the peak level of 1974.

---

[6] In order to be able to interpret this data extensively it would also be necessary to investigate, in how far investment in pollution control does, at the same time, lead to optimization of processes and, thus, to increased returns.

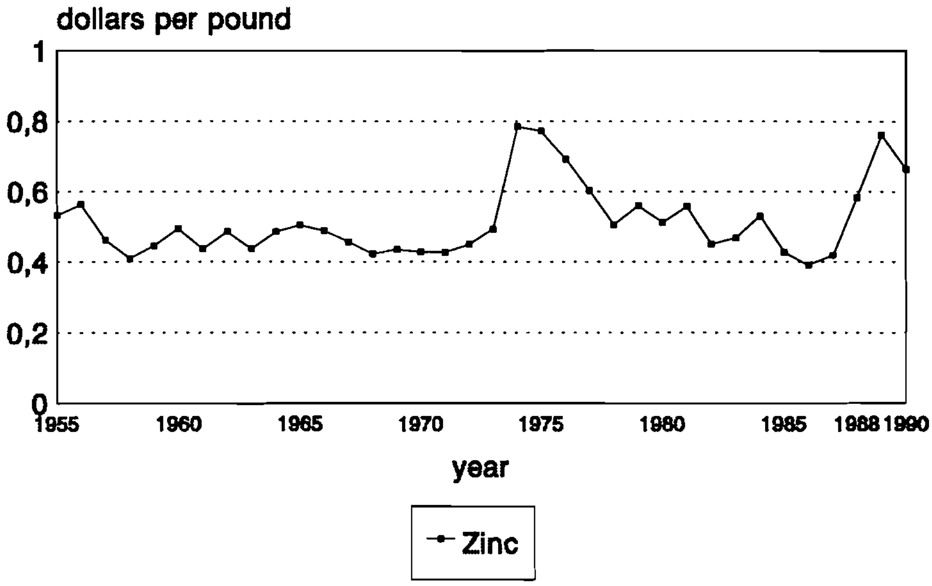
[7] Regional producer prices exist, as e.g. the European producer price.

[8] While the US producer price in the mid 80's dropped by 30%, zinc prices in Germany declined by over 50% [Clark 1986].

Figure 2.1.

Average Annual Prices of Zinc

1955 to 1990 in Dollars per pound
Based on Constant 1987 Dollars

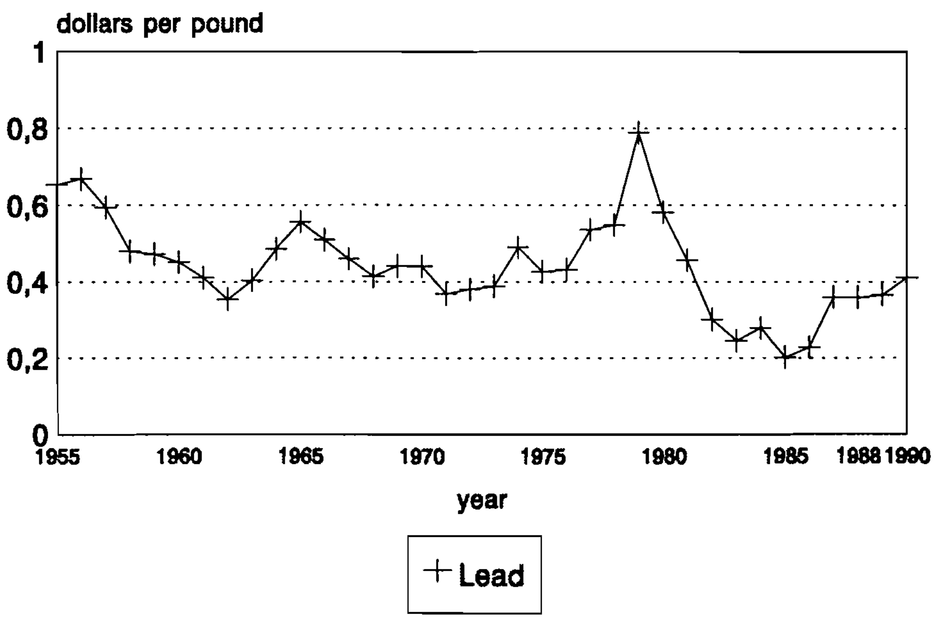


Source: U.S. Bureau of Mines 1992.

Figure 2.2.

Average Annual Prices of Lead

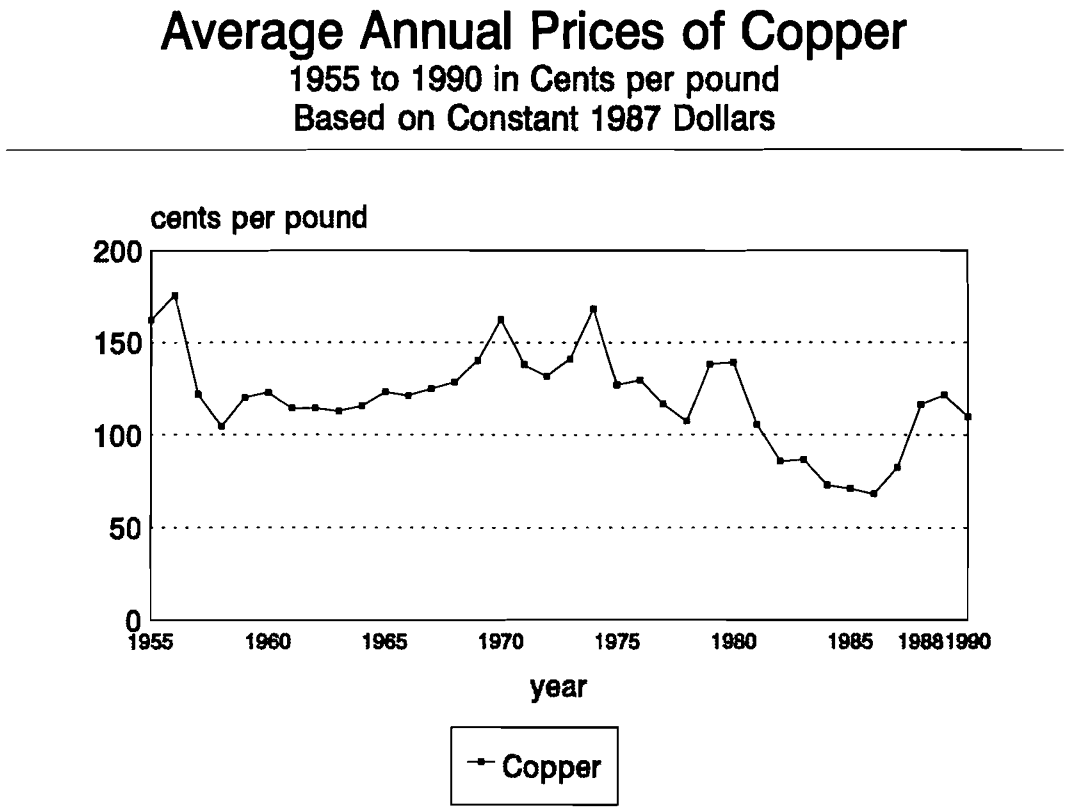
1955 to 1990 in Dollars per pound
Based on Constant 1987 Dollars



Source: U.S. Bureau of Mines 1992.

Lead prices decreased from the mid fifties. Increasing demand led to price increases between 1962 and 1965 [Gebhardt/Knörndel 1977]. Prices then declined again. From the early 70's there was an increasing trend, reaching the highest price level in 1979. This was followed by a rapid decline, leading to the lowest price level during the time period investigated in 1985. Lead prices then increased again.

Figure 2.3.



Source: U.S. Bureau of Mines 1992.

Copper prices also declined around the mid fifties. In the early 60's they were stabilized at a low level by the big producers trading on the stock exchange. Only since 1964 have copper prices mirrored market developments [Gebhardt/Knörndel 1977]. Prices increased until 1974, with an interim drop around 1972. In 1974 copper prices dropped and mirrored the beginning of a copper crisis [Gebhardt/Knörndel 1977]. The prices declined - except for a short increase around 1980 - until the mid 80's and only then started to rise again.

2.6. Conclusions

While the non-ferrous metal industry in West-Germany is of only minor importance, compared to the rest of industry, with respect to economic indicators such as employment and turnover, it plays a strategic role as a base industry for the economy. Its importance can mainly be seen in securing the supply of resources to downstream industries and as purchaser of products from other sectors.

Owing to limited ore resources in Germany the production of non-ferrous metals relies heavily on imported raw materials. This makes metal prices, prices for raw materials and transport costs crucial factors for its economic and competetive position. Secondary production is, therefore, an important alternative to primary production. Until 1980 there were - except for lead production - no relevant shifts to secondary production, but since then the share of secondary metal production has increased continuously [Steil 1993]. Increasing waste disposal costs due to stricter environmental law may also have been important for this development.

Being a highly electricity-intensive industry, the costs for electricity are also crucial for the economic well-being of non-ferrous metal production. High electricity costs combined with low zinc prices put for example the electrolytic zinc plants under economic pressure at the end of the 70's and during the 80's.

A further important cost factor is represented by environmental protection requirements, as set in the `technical directions air' or required by local authorities. Between 1975 and 1985 the share of investment in environmental protection in the total investment for Germany's non-ferrous metal refineries grew by about 22 percentage points. These expenses could only be met because enterprises accepted losses in the interest of maintaining refineries as part of their overall production strategy. The cost of environmental protection is also seen as a factor resulting in stronger concentration and rationalization of non-ferrous metal production.

The cost factors mentioned above are particularly significant for the economic situation of the non-ferrous metal industry as metal prices are mainly set on the metal stock exchange. National costs cannot, therefore, be easily passed on and compensated for by price increases.

Relevant for the cost situation of the non-ferrous metal industry were the relatively low zinc price during the sixties and early seventies and its significant decline between 1975 and 1986, the distinct drop in the lead price during the first half of the eighties and the declining trend in the copper price between 1974 and 1986. Provided that secondary metal production is less expensive than primary production, the decrease in metal prices during the early 80's may have been a further factor relevant to the increase in secondary production during this period.

3. Air Pollution Control

The development of legal framework with respect to air pollution control is described in this chapter. This is a second factor behind intrasectoral change. Relevant to non-ferrous metal production in the Ruhr Area (Northrhine-Westfalia) is, on the one hand, the federal legislation, given in the `technical directions air', and, on the other hand, Northrhine-Westfalia's clean air planning.

3.1. Legal Framework

Before 1964 technical standards for plants were determined by the `industrial code' (Gewerbeordnung). According to the `technical directions air', i.e. TA-Luft 1964, 1974, 1983 and 1986 *new plants* are only to be authorized, if

a) they are equipped with the best available technology for the limitation of emissions,

b) the immission standards are not exceeded due to the new plant and

c) those emissions which, even using the best available technology, are unavoidable are adequately dispersed.

Exceptions with respect to equipment with the best available technology are possible, if it is guaranteed that the immission standards are not exceeded by other means e.g. other technologies, higher chimneys, different fuel input, diminution of the plant or a reduction of emissions from other plants run by the applicant [TA Luft 1964; TA Luft 1974].

New federal legislation imposed since June, 1960, enabled authorities for the first time to command technically feasible and economically reasonable measures for *existing plants.* Plants affected were listed in an ordinance[9] of August 1960. In 1962 Northrhine-Westfalia enacted its clean air law[10] designed to reduce pollution from plants not covered by federal legislation [Blazejczak 1995].

According to the `technical direction air' 1974, clean air plans are to be set up for areas in which detrimental effects on the environment due to air pollution exist or where they are to be expected. These plans consist of information on the expected air pollution, its effects on the environment, the sources of air pollution and proposed measures to reduce emissions [TA Luft 1974].

3.1.1. `Technical Directions Air' (TA Luft)

In the *TA Luft 1964* immission standards for dust and gases were fixed, however, heavy metal deposits were not yet mentioned. In regard to the non-ferrous metal industry various standards and technological requirements were set: for SO_2 and dust emission resulting from lead, copper and zinc production. An

---

[9] Verordnung über genehmigungsbedürftige Anlagen.

[10] Landesimmissionsschutz-Gesetz.

example of the technological demands is the installation of plants for the production of sulphuric acid from roasting and sinter off-gases [TA Luft 1964].

Specific emission standards for lead, copper and cadmium in dust were first set in the *TA Luft 1974*. In order to reduce dust emissions various, mainly organizational-technical measures are required by *TA Luft 1974 and 1983*. These measures[11] cover such treatment as storage, transport, conveyance, discharge, and maintenance of moisture level for dusty comminution materials, goods and production residues, as well as the collection of dust containing waste gases.

Special requirements with respect to dust, gaseous and SO_2-emissions[12] were imposed for unrefined non-ferrous metal production facilities and for foundries [TA Luft 1974; TA Luft 1983].

In *TA Luft 1986* standards for emissions were tightened. Specific values for dust emissions from lead smelting facilities were also tightened. Existing plants with emissions of cadmium, arsenic and sulphur dioxide had to fulfil the new requirements by March 1st, 1991 [TA Luft 1986].

Waste gases which include dust from non-ferrous metal smelters and refineries had to be collected and fed into dedusting systems. Specific emission standards were imposed for dust emissions in waste gases from lead smelters and refineries, and for the copper content of waste gas from furnaces, in which cathode copper is smelted.

3.1.2. Clean Air Planning in Northrhine-Westfalia

Previously the state government of Northrhine-Westfalia had tried to reduce the air pollution from industrial dust and sulphur dioxide emissions with help of sectoral amelioration programmes (focussing for example on steel-converters, cement and coking plants). More recently the concepts were extended to a regional focus, including all industries responsible for air emissions and all kinds of emissions. Clean air plans (Luftreinhaltepläne) were set up for 3 regions within the Ruhr Area: Ruhr Area West, East and Centre. The first generation of these plans covered the years 1976 to 1982, the second, the years 1983 to 1988 [MURL 1989].

The area most affected by heavy metal emissions is the western part of the Ruhr Area. Measures that were to be taken in the period 1978 to 1982, as stated in the clean air plan for Ruhr Area West and related to the non-ferrous metal industry, cover mainly organizational-technological measures such as covered storage of raw materials at refineries or mineral grinding mills and the covering of the conveyor belts [MAGS 1977].

During these years the actual reduction in dust emissions was more than double what had been aimed at in the first clean air plan. Still, several measurements showed that immissions of lead, zinc and cadmium were higher in some areas than allowed by the standards. The aim of the second clean air plan for Ruhr

---

[11] For more detailed information see Annex I/A.1.

[12] For more detailed information see Annex I/A.2.

Area West was therefore to reduce dust emissions and their heavy metal content in order to meet these standards. Concrete measures were however not specified [MAGS 1985].

Relevant measures to be taken in the period 1979 to 1983 as stated in the clean air plan for Ruhr Area East [MAGS 1978] are the washing of gases, combined with the use of drop separators, in order to reduce emissions of zinc sulphate and sulphuric acid which are contained in low concentrations in the gases produced by electrolytic zinc refining.

In 1989 information about the levels of dust and fly dust deposits within the time period of clean air planning for Northrhine-Westfalia was published[13]. A comparison of deposits and immission standards according to the TA Luft 1986 is presented below[14]. Immission standards[15] were set for: dust deposits, lead contained in dust deposits, cadmium contained in dust deposits, fly dust deposits, lead compounds contained in fly dust deposits and cadmium compounds contained in fly dust deposits.

In 1988 there was, in general, a very low deposit of dust and fly dust, as well as of contained lead and cadmium compounds. Still, immission standards were exceeded in the areas around Duisburg (Ruhr Area West), Datteln (Ruhr Area East) and in the Ruhr Area Centre [MURL 1989]. Since 1968 fly dust deposits declined considerably. While in the Ruhr Area West dust deposits containing lead declined from 1982, they rose in the other areas until 1985. After 1985 dust deposits containing cadmium also declined in all areas.

3.2. Conclusions

In the early sixties immission standards and technological requirements relevant to the non-ferrous metal industry were set for SO_2 and dust emissions (see \`technical direction air' 1964). Specific emission standards for lead and cadmium contained in dust were set, for the first time in the \`technical direction air' 1974 and tightened in the \`technical direction air' 1986.

Measures required by \`technical direction air' 1974 and 1983 and aimed at reducing dust emissions covered mainly organizational-technical measures for the following treatment: storage, transport, conveyance, discharge, and the collection of dust containing waste gases. For the non-ferrous metal industry further specific requirements were set for various facilities, e.g. foundries, reducing dust, gaseous, and SO_2 emissions.

While measurements of emissions in Northrhine-Westfalia during the early eighties in connection with clean air planning showed that emission reductions had been higher than required by the first generation of clean air plans, immissions of heavy metals in several areas did not meet the specified standards. The second generation of clean air plans, therefore, aimed at the reduction of dust emissions and the heavy metals that they contained.

---

[13] MURL 1989.

[14] For more detailed information see Annex I/B.2.

[15] The immission standards according to TA Luft 1986 are presented in Annex I/B.1.

Measurements of immissions at the end of the eighties showed generally low deposits of dust, fly dust, and the lead and cadmium compounds they contained. Still, immission standards were exceeded in the Ruhr Area, mainly in the areas of heavy industry around Duisburg and Datteln. Since the mid-eighties, however, deposits have declined in the entire Ruhr Area.

With respect to the hypotheses put up in chapter 1.4., it can be assumed that the tightening of legal requirements over the time period investigated influenced the technologies (process technologies as well as end-of-pipe technologies) applied within the the sector of non-ferrous metals and also led to an increase in organizational-technical measures taken.

Also, changes in the economic framework (see chapter 2.) - e.g.changes in metal prices and the effects of the oil crises on energy costs - can be assumed to have been important for decisions regarding technologies, capacities and concentration processes.

4. Restructuring of Non-Ferrous Metal Production in the Ruhr Area

The main aim of this chapter is to identify the intrasectoral changes - relevant to heavy metal pollution - within the Northrhine-Westfalian non-ferrous metal industry and the driving forces behind these changes.

As a first step, the economic development of the non-ferrous metal industry in Northrhine-Westfalia is described. In a second step aspects of intrasectoral change in the industry are investigated at the level of individual plants.

4.1. Development of the Non-Ferrous Metal Industry in Northrhine-Westfalia

Ore Mining

In Northrhine-Westfalia several metal ore deposits are to be found. In 1958 metal ore concentrates were produced in 7 ore mines and 1 pyrites mine, two of them being situated in the Ruhr Area, near Essen and Marl. Owing to exhaustion of mines and the lack of profitability of mining, caused by the decline in zinc and lead prices since 1957, four out of the 7 ore mines were closed down between 1960 and 1970. By 1978 only the mine Lüderich, near Köln, was still in use [Wettig 1980]. The process of ore mine closures continued until 1992 when the very last ore mine (situated in Meggen) in Germany was closed down [Steil 1993].

Non-Ferrous Metal Production[16]

The main part of the German non-ferrous metal production and manufacturing is situated in Northrhine-Westfalia, due to favourable conditions of location, e.g. a good supply of raw materials[17] and energy, good access to transport, and the proximity of metal manufacturers and users.

Iron and metal production plays an important role in Northrhine-Westfalian industry. In 1976 12% of all industrial employees were employed in iron and metal production, 42% in iron and metal manufacturing industries, 12% in the chemical industry and 10% in the mining and stones and clays industries [Wettig 1980].

Whilst there was a slow decline in most industrial sectors between 1958 and 1974, there was an increase in employees in the non-ferrous metal and the iron and metal manufacturing industries. The recession of 1975 and 1976 had particularly severe effects on the Ruhr Area, being the centre of heavy industry in Northrhine-Westfalia. Employment in the non-ferrous metal industry was reduced by 13% [Wettig 1980].

---

[16] Included are refineries, foundries, re-melting plants and the production of semi-finished products.

[17] This, however, is more important for primary than for secondary refineries.

4.2. Plants in the Ruhr Area (Northrhine-Westfalia)

Currently existing plants[18]:

- *M.I.M. Hüttenwerke Duisburg GmbH*, (MHD Berzelius Duisburg, GmbH) producing zinc, crude lead, sulphuric acid, copper.
  Formerly:
  Berzelius Metallhütten GmbH in Duisburg, thermic lead-zinc refinery. Producing lead and zinc.
  Primary smelter (Imperial Smelting Process - ISF), roaster and sulphuric acid plant and hot-briquetting plant.
  Refinery: New Jersey process (electrothermic zinc refinery).
  Capacity:
  Lead smelting and refining works: 35,000 tonnes/year
  Zinc smelters: 90,000 tonnes/year
- *Berzelius Stolberg* in Binsfeldhammer[19] near Aachen: producing lead.
  The primary smelter produces lead (QSL technology), using concentrates and lead-containing residues as raw materials.
  The refinery produces refined lead and doré silver, using lead bullion as raw material.
  Previously: lead smelter. Processes: roasting and sulphuric acid plant and refinery.
  Capacity:
  Lead smelting and refining works: 80,000 tonnes/year
- *Stolberger Zincoli GmbH* in Stolberg[20]. Zinc dust plant.
  Established in 1960.
  Producing zinc powder and dust, using zinc residue and metal.
- *Ruhr-Zink GmbH* in Datteln.
  Electrolytic zinc refinery, producing zinc, cadmium, copper, zinc alloys and germanium.
  Previously: smelter and refinery [Metal Bulletin 1982].
- *Hüttenwerke Kayser A.G.* in Lünen, running copper smelters and refinery.
  Electrolytic refinery and secondary ingot plant using copper

---

[18] Compare in addition to the cited authors: ABMS several volumes; yearbook 1995; Metal Bulletin 1993.

[19] Binsfeldhammer is situated outside the Ruhr Area part of Northrhine-Westfalia.

[20] Stolberg is situated outside the Ruhr Area part of Northrhine-Westfalia.

and secondary materials to produce copper - high grade electrolytic cathodes.
Previously only electrolytic copper refinery, using shredder material, cupreous residues, brass, gunmetal and copper refining material and blister copper as raw materials to produce electrolytic copper, tin alloy, zinc oxides, copper sulphate and nickel sulphate [Metal Bulletin 1982].
Capacity:
copper smelter: 105,000 tonnes/year
copper refinery: 122,000 tonnes/year

- *Muldenhütten Recycling und Umwelttechnik GmbH* in Duisburg. Conventional lead refinery using crude lead as raw material. Secondary ingot plant producing lead CX battery breaker and short rotary furnaces using scrap batteries, scrap lead and lead residues as raw materials.

Previously existing plants:

- *Duisburger Kupferhütte GmbH.* This plant consisted of copper and zinc smelting plants and was closed down in 1983. Today only iron is produced. The zinc plant was opened in 1958, using the electrothermic process [Bayer 1960].
- *Stolberger Zink AG* in Münsterbusch near Stolberg and in Nievenheim[21], producing zinc. The plant in Nievenheim was closed down in 1962, the one in Münsterbusch in 1967 [Wettig 1980].
- *AG des Altenbergs* in Essen-Borbeck, producing zinc. The plant was closed down in 1968 [Wettig 1980]

Until the end of the 60's the production of sulphuric acid was continued in the plants in Essen and Nievenheim [IHK 1973].

4.2.1. Ruhr-Zink GmbH Datteln[22]

The electrolytic plant Ruhr-Zink GmbH was built in 1968 with an average capacity of 80,000 tonnes/year (maximum about 116,000 tonnes/year). In 1975 a new electrolysis unit was built and the capacity increased to 131,000 tonnes/year. In 1992 it had a capacity of 140,000 tonnes/year [Röseler 1992].

---

[21] These plants are also situated outside the Ruhr Area part of Northrhine-Westfalia.

[22] For basic information on technologies see Annex II/A.

Share holders are the Metallgesellschaft AG, Frankfurt, the Australian Mount Isa Mines Ltd.[23] and VEW[24], Dortmund.

Reasons for the decision in 1968 to locate the plant in Datteln were the proximity of the Ruhr Area's big steelworks, the availability of a low cost energy supply, as coal prices had declined considerably in the late 60's, and good access to train, road and canal, especially to the habours of Rotterdam and Antwerpen due to nearby waterways (Dortmund-Ems-Kanal) which allowed the transport of zinc concentrates[25] and sulphuric acid necessary for zinc refining [Metall 1968].

In the 70's the economic framework changed, e.g. the price of coal increased due to the oil crises. In the long term only electrolytic zinc plants with a minimum capacity of 200,000 tonnes/year were thought to be profitable. Additionally - because of the rising public interest in environmental protection - it was doubtful whether simply an expansion of production would be authorized. As a consequence it was decided at the end of the 70's to increase the capacity to 200,000 tonnes/year and at the same time to improve processes and increase the re-use of residues in order to reduce emissions and waste. The aim was to reduce energy consumption and to reduce emissions, not only with help of end-of-pipe technologies but to prevent the generation of dangerous substances within the process with help of process innovations, and to sell as much of the substances still arising as possible [Röseler 1992].

The modernization process lasted until around 1990. In Datteln zinc is now produced in a hydrometallurgical process consisting of 6 production steps. Each of these is responsible for specific environmental problems. The residues include sulphuric acid as well as gypsum, that can both be re-used. Further by-products include gas emissions which are reduced with help of filters to levels below the standards set by the TA-Luft, zinc solutions, containing zinc and iron, lead-zinc-concentrates that are delivered to a lead refinery, copper cement, that is sold, cadmium, that is used to produce cadmium metals and iron residues (goethite or jarosite) that have to be carefully disposed of. These pose the worst problem for the electrolytic process [Röseler 1992].

Secondary materials are not used, as the electrolytic process is very sensitive to impurities. The zinc produced has a purity of almost 100%. One reason for building a new hall for the electrolytic process was to reduce energy inputs, as electricity costs had increased considerably since the late 60's. Energy use was cut by 7%.

In this hall gases are completely extracted by suction, washed and cleaned by filters, leading to a cleanness of the gas higher than required by the TA-Luft. The high environmental standard achieved is, to a large extent, based on highly developed end-of pipe technology, as not all substances arising within the production are re-used.

---

[23] M.I.M. has held shares since the early eighties, when Metallgesellschaft decided to sell parts of their shares because of losses within the zinc refineries [Chem. Ind. 1982].

[24] Vereinigte Elektrizitätswerke Westfalen AG.

[25] They are imported from Australia, Turkey, Canada, Peru and Mexico.

Remaining environmental problems are the emissions of SO_2 and dust and the residue jarosite. The problem of SO_2 and dust emissions is supposed to be solved by a new roasting and leaching process technology (developed by Sheritt-Gordon), the production of jarosite is supposed to be prevented by installing a new hematite[26] process, that makes the re-use of residues possible, but is, at the same time, more cost-intensive [Röseler 1992].

4.2.2. Berzelius Stolberg[27]

In 1990 the older sinter plant and shaft furnace were closed down and the QSL reactor, a single stage process, opened. This new technology cuts sulphur dioxide and lead emissions [Anyadike 15th March 1990] and allows the processing of secondary raw material more cost effectively [Matzke 1988]. The former roasting reaction processes had been criticized because of their high emissions of SO_2 and heavy metals. With the new process decreases in emissions of dust (-20%), cadmium (-90%), zinc (-60%), lead (-30%), arsenic (-65%) and sulphur dioxide (-90%)[28] were expected. The former process had led to yearly emissions of 30 tonnes lead dust, 7 tonnes zinc and 250 kg arsenious oxide. While in 1970 lead emissions amounted to 40 kg/tonne lead, they are now reduced to 5 kg/tonne lead [Vennen 1991; Matzke 1988; BddW 1982][29].

Between 1981 and 1986 a demonstration plant[30] for the QSL process was in operation at the Berzelius Duisburg zinc plant [Anyadike 15th March 1990]. The development of this process was pursued as a joint venture by Metallgesellschaft and Preussag Aktiengesellschaft Metall, West Germany's two major producers of non-ferrous metals. The German Ministry of Research and Technology[31] provided about half the financial support required for the programme, including construction and two years' demonstration testing [E&MJ 1983]. The West-German government contributed grants worth 16% and Northrhine-Westfalia around 5% of the start-up cost of about DM 100 million of the new plant in Stolberg.

The slag arising from the QSL process (with an expected lead content of approximately 0.5% at the beginning of this process) can be used in road construction. The QSL reactor was supposed to first

---

[26] In 1979 the smelter was first converted to using hematite technology [Ehrenberg 1986]. At that time the process only achieved an iron content of 55% in hematite, which was regarded as too low by the steel industry. Therefore hematite was sold to the cement industry [Ehrenberg 1986]. In a pilot operation Ruhr Zinc was able to raise the iron content to around 62% which might meet steelmakers' requirements.

[27] For basic information on technologies see Annex II/B.

[28] With respect to the emission reductions different figures are stated in different sources. E.g. "sulphur dioxide and lead emissions are reduced to 5%".

[29] End-of-pipe technologies to reduce these emissions were, however, already installed within this time period. This was due to pressure from neighbouring inhabitants.

[30] The costs of this demonstration plant of about DM 25 million were financed to about 50% by the German Ministry of Research and Technology (Ministerium für Forschung und Technologie). It had an average capacity of about 30,000 tonnes/year [BddW 1982].

[31] Bundesministerium für Forschung und Technologie.

process zinc leach waste from the Duisburg plant and later on lead ashes, residues from filter cakes, slags, refinery dust and glass containing up to 60% lead [Anyadike 15th March 1990].

The residues from lead refining that had previously only been re-used to a small extent were supposed to be recycled to a greater extent. For this purpose a number of sub-works were built, producing for example sulphuric acid, energy, cadmium carbonate and silver [Vennen 1991]. Residues from the plants in Duisburg and Datteln are also recycled. The plant requires an energy input of 40% to 50% below that of the older process technology.

The investment costs of the QSL-process are 60%-70% and the running costs 60% of those of a conventional plant [Matzke 1988]. The plant meets the demands set by the TA-Luft 1986 with respect to for example recycling and the prevention of emissions with the help of process technologies.

In 1994 it was planned to switch production from a ratio of 60% primary and 40% secondary to a production of 70% secondary and 30% primary and to cut total output by 20,000 tonnes/year according to a restructuring plan from the owner, Rheinische Zinkgesellschaft. The new production programme was supposed to be economically better, because the concentrates are expensive [Metal Bulletin 19.9.1994].

4.2.3. Berzelius Duisburg[32]

The Berzelius Metallhütten GmbH was founded in 1905. In 1907 the zinc production started using the intermitted retort process and in 1935 a refinery using the New Jersey process was opened, achieving zinc qualities of almost 100%. In 1958 the Delplace roasting process was replaced by a sintering process which was again improved in 1964[33] [Oberbeckmann 1980].

Up until the mid 60's the Berzelius Duisburg works consisted of a zinc-only smelter using the above mentioned intermitted retort process. In the mid 60's a fundamental modernization programme was carried out. In the years 1964 and 1965 the gas cleaning plant was expanded and a new process[34] for sulphuric acid production was introduced [Oberbeckmann 1980]. The modernization process involved the replacement of the retort furnaces by an Imperial Smelting Furnace. Starting in 1965 this constituted a move away from the zinc-only smelter to a zinc-lead smelter, producing zinc and lead [Clark 1986].

With the continuous Imperial Smelting process it became possible to produce zinc in larger production units. The retort furnaces were closed down between 1965 and 1967, partly due to the weak zinc-metal market. In 1969 a cadmium leaching plant processing cadmium contained in flue dust, stemming from the sinter plant, was started and in 1974 a new zinc refinery was built. Also at the end of the 60's the

---

[32] For basic information on technologies see Annex II/C.

[33] Replacement of suction draught by pressure sintering. In 1962 5 out of 12 retort furnaces were equipped with collecting condensers that increased the output and reduced working hours.

[34] Double catalyst process.

Imperial Smelting process was improved, aiming at higher flexibility, i.e. the possibility of using secondary materials and of recovering other metals [Oberbeckmann 1980].

The ISF-smelter made it possible to use new raw materials - mixed concentrates instead of the pure zinc concentrates previously required - as well as secondary raw materials. Particular emphasis was placed on the use of secondary materials and in 1975 a significant step towards more intensive recycling was taken with the start-up of a hot briquetting plant for oxidic secondary materials. In 1979 this was followed by the construction of a receiving station in conjunction with a large store for 5,000 tonnes of ashes and residues [Clark 1986]. As a result, in the mid 80's about one third of the company's metal production came from secondary materials. Since 1987 zinc-containing steelworks dust from electric furnaces is also used as a raw material in the ISF-process.

Apart from increased recycling the second policy pursued by the company was a greater concentration on co-products, such as cadmium and copper, which was made possible by the increased flexibility provided by the ISF-process. The works has a plant for the production of cadmium carbonate, which is sold to the Ruhr Zink electrolytic zinc refinery and, since 1974, a small electrolytic copper refinery for the extraction of copper from crude lead. In the mid 80's Berzelius produced about 80,000 tonnes/year of zinc, of which about 40,000 tonnes/year were refined using the New Jersey system [Clark 1986; Oberbeckmann 1980].

4.2.4. Duisburger Kupferhütte GmbH

Oxidic residues were recycled with help of chemical hydro- and pyrometallurgical processes. Raw materials used were oxidic copper- and/or zinc-containing residues. Granulated zinc oxide with extremely low heavy metal contaminations, blister copper, sodium sulphate, foundry pig iron, cobalt and ferro-cobalt granules and cobalt oxide were produced [Metal Bulletin 1982].

The copper producing plant was closed down in the early eighties because it was old and unprofitable. Today the enterprise, now called "DK Roheisen und Recycling", produces only iron from iron containing residues such as dust and secondary materials.

4.3. Development of Capacity

In the following table the development of non-ferrous metal production capacities in the Ruhr Area and the plants situated around Stolberg is presented.

Table 4.1.

Capacity in Tonnes per Year					
Lead Refing					
	1956	1966		1976	Early 90's
Berzelius Duisburg	(-)	(-)		35,000 (1)	35,000
Berzelius Stolberg	50,000	75,000		80,000	80,000
Total	50,000	74,000		115,000	115,000
Zinc Refing					
	1956	1966	1968	1976	Early 90's
Ruhr-Zink GmbH	(-)	(-)	80,000 (2)	150,000	140,000
Duisburger Kupferhütte	(-)	20,000		20,000	(-)
Berzelius Duisburg	33,000	33,000		90,000	90,000
AG des Altenberg (Essen-Borbeck)	30,000	29,000		(-)	(-)
Stolberger Zink AG					
Münsterbusch	32,000	30,000		(-)	(-)
Nievenheim	17,000	24,000		(-)	(-)
Total	112,000	136,000		260,000	230,000
Copper Refing					
	1956	1966	1970	1976	Early 90's
Hüttenwerke Kayser AG					
smelter					105,000
refinery	32,000	42,000	75,000	85,000	122,000
Duisburger Kupferhütte	(*)	(*)	30,000	30,000	(-)
Total	>32,000	>42,000	105,000	115,000	227,000

(1) Production of crude lead only.
(2) Average annual capacity, maximum capacity 116,000 tonnes.
(*) No data.
(-) No production.
Sources: Wettig 1980; ABMS several volumes; ABMS 1971; Röseler 1992.

The gradual increase in capacity of *lead production* over the whole period investigated was due firstly to an increased capacity of the Berzelius Stolberg plant, secondly to the switch from a zinc-only to a lead-zinc smelter at Berzelius Duisburg.

Though three old zinc plants were closed down during the 60's, the *zinc production* capacity in Northrhine Westfalia rose until the early eighties, owing to the opening of the Ruhr-Zink GmbH and an increased production at Berzelius Duisburg. This gives an indication of the concentration processes, that may have been due to changes in the economic framework, e.g. rising energy costs. The closure of Duisburger Kupferhütte contributed to the decline in capacity until the early 90's.

Though there was no data available on the capacity of Duisburger Kupferhütte for the early years, it can be assumed that *copper production* capacities in Northrhine-Westfalia increased over the whole period of investigation. This was due to a gradually increasing capacity of the plant Hüttenwerke Kayser AG, which more than compensated for the decline in capacity due to the closure of Duisburger Kupferhütte in the early eighties.

4.4. Aspects of Change - Conclusions

4.4.1. Developments Until the Early 70's

Measurement of emissions started in Duisburg in 1953 and focused on emissions from chimneys. With developing off-gas cleaning technologies it became obvious, that emissions from stocks, transport, reloading points and open plants added a considerable share to the total emissions and had to be also taken into consideration [IHK 1973].

Two *copper producing plants* are situated in the Ruhr-Area, the Duisburger Kupferhütte and Hüttenwerke Kayser AG in Lünen, the latter processing only secondary materials [Wettig 1980].

Between 1969 and 1972 mainly organizational-technical measures were taken in order to decrease dust emissions from stocks, transport and reloading within the production of copper, such as covering of storages and storing in silos and halls, moisting of slags, covered transport and the installation of roofs over conveyor belts [IHK 1973].

During the 60's three *zinc producing plants* were closed down, as they could no longer be run profitably due to their old facilities. Zinc production was closed down in Nievenheim in 1962, in Münsterbusch in 1967 and in Essen in 1968 [Wettig 1980]. While the zinc production at the plants had already been closed, the plants in Essen and Nievenheim continued roasting processes, producing sulphuric acid, until they were finally closed down around 1970 [IHK 1973].

In 1968 the Ruhr Zink plant in Datteln was opened. Zinc production was now only pursued in three plants[35]: Ruhr Zink AG in Datteln, Berzelius Duisburg GmbH and Duisburger Kupferhütte.

In the mid sixties a fundamental modernization programme started at Berzelius Duisburg which involved the replacement of the older retort furnaces by the Imperial Smelting process[36], and facilitating the use of secondary materials and the production of by-products from residues.

At each of the remaining plants a different technology was employed [IHK 1973; Schackmann 1972]:

- the zinc electrolytic process at the Ruhr Zink AG in Datteln,
- the ISF-process at the Berzelius Duisburg GmbH, and
- the electrothermic process at Duisburger Kupferhütte.

Zinc electrolytic plants are less emission intensive than electrothermic processes and meet the standards set for dust emissions [Metal Bulletin Ltd. 1978].

Apart from the secondary producer Muldenhütten Recycling and Umwelttechnik GmbH in Duisburg, two *lead refineries* are situated in Northrhine-Westfalia: Berzelius Stolberg and Berzelius Duisburg, the latter has been producing lead since 1965. By 1971 the newer of two lead refineries in Northrhine-Westfalia had pursued various improvements to decrease dust emissions. For the second refinery a programme was set up, aimed at the reduction of dust emissions and at increasing the share of gas in input energy. As in refineries run with gas the health and safety regulations require lowest dust concentrations, health requirements and environmental protection go hand in hand [IHK 1973].

4.4.2. Developments Until the Early 90's

In the `technical directions air' of 1974 and 1986 increasingly strict standards were set for dust and heavy metal emissions which required improvements in end-of-pipe technologies and organizational-technical measures in the non-ferrous metal industry to decrease emissions from for example stocks, transport and reloading points.

---

[35] A fourth plant, the Stolberger Zincoli GmbH established in 1960, produces only zinc powder and dust from secondary materials.

[36] The ISF-process was installed in 1965. Since then zinc and lead are produced.

Due to increased energy costs and a rising public interest in environmental protection the decision was made at the end of the 70's to modernize processes and increase *zinc production* at the Ruhr Zink GmbH. This modernization process lasted until the early 90's and led to a reduction in energy consumption and emissions and to an increase in recycling.

The *copper and zinc* producing plant at Duisburger Kupferhütte was closed down in 1983, as it was obsolete and could no longer be run profitably.

In 1990 the old sinter plant and shaft furnace at the *lead producer* Berzelius Stolberg were closed down and replaced by the single stage QSL process. This modernization led to considerable decreases in emissions and made secondary production and a re-use of residues possible.

At Berzelius Duisburg, the Ruhr Area's *lead-zinc production* plant, measures aimed at an increased use of secondary materials were taken during the 70's, such as the start-up of a hot briquetting plant for oxidic secondary materials in 1975 and the construction of a receiving station and a store for secondary materials. Emphasis was also placed on the production of by-products such as cadmium carbonate and copper. In 1974 a small electrolytic copper refinery was built.

4.4.3. Conclusions

Changes within the non-ferrous metal industry relevant to the decline in heavy metal emissions during the time period under investigation consisted, in the first place, of the application of new process technologies, including a closing of material circles, thus resulting in input changes and a decrease in waste, of the application of improved end-of-pipe technologies and of growing organizational-technical measures. A second important aspect was the closure of environmentally and economically obsolete plants.

The fact that production capacities increased over the time period investigated while heavy metal emissions declined, also gives an indication of modernization and concentration processes having taken place within the non-ferrous metal industry. This development also stresses the results of earlier research [see De Bruyn/Schucht 1996], that intrasectoral change was of major importance for the decline in emissions caused by non-ferrous metal production.

5. Conclusions and Outlook for Further Research

One purpose of this paper was to investigate *intrasectoral changes*, i.e. changes that took place within the non-ferrous metal industry, that have contributed to the decline in heavy metal emissions since the mid 60's. Intrasectoral change comprises product and process related changes, the installation of end-of-pipe technologies and substitution of inputs. Also closures of plants may have been important for the reduction of heavy metal emissions in the Ruhr Area (Northrhine-Westfalia). Although capacities were increased, in existing plants and by the opening of new plants, these higher capacities were produced with modernized technologies, that are less emission intensive than those used in the older plants. A second purpose was the investigation of *driving forces* behind these changes, such as developments in the legal framework, changes in the economic framework, and a rising public interest in pollution control.

5.1. Conclusions

Aspects of Intrasectoral Change

Measurements of emissions from industrial plants had already started in Northrhine-Westfalia in the early 50's. While some off-gas cleaning technologies were already installed in the 60's, in the following years more emphasis was placed on emissions from for example stocks, transport and reloading points, as well as on improvements in technologies. Not only were filters continuously improved, but also new process technologies were applied.

For the destinct decline in heavy metal emissions that have occured since the mid sixties with respect to zinc and cadmium, and since the early seventies with respect to lead, the following developments that took place in the Ruhr Area (Northrhine-Westfalia) may have been of influence:

- Three old zinc producing plants were closed down between 1962 and 1968.
- The Ruhr Zink AG Datteln, opened in 1968, was equipped with a modern electrolytic technology which is less emission intensive than the older electrothermic processes. During the 80's a modernization process took place at this plant, which increased the capacity and at the same time saved energy, increased recycling of residues and decreased emissions and residues.
- In 1965 the old intermitted retort process at Berzelius Duisburg was replaced by the Imperial Smelting process.
  This constituted a move away from the zinc-only to a zinc-lead smelter and made the use of mixed concentrates and secondary materials possible.
  At the end of the sixties and during the seventies sub-works for the production of by-products and increased recycling were opened.
- The copper and zinc producer Duisburger Kupferhütte was closed down in 1983.

- At Berzelius Stolberg a completely new refining process (QSL process) was installed in 1990, replacing the old sinter plant and shaft furnace.
  This cut down emissions considerably and, together with the installation of several sub-works, made secondary production and recycling of production residues feasible.

These developments confirm the hypotheses put forward in chapter 1.4. that intrasectoral change relevant to the emission of heavy metals consisted mainly of process changes, including an increased processing of production residues, and of improved end-of-pipe technologies.

The increase in production capacity coupled with decreasing emissions over the time period investigated, also gives an indication of modernization and concentration processes having taken place within the non-ferrous metal industry and confirm the assumption that intrasectoral changes have been of major importance for the decline in emissions caused by non-ferrous metal production. The replacement of environmentally and economically obsolete plants by modern, higher capacity plants also contributed to the decline in emissions.

Driving Forces of Intrasectoral Change

Driving forces of intrasectoral change consisted mainly of three components:

- legal requirements,
- economic motivations of the enterprises, i.e. the aim to reduce costs and to increase returns, and
- financial support given by public authorities.

Regarding the development of legal framework, immission standards for dust were first fixed in the `technical direction air' of 1964. Standards for heavy metal emissions and immissions were set in the `technical direction air' 1974 and tightened in its amendment of 1986. In the `technical direction air' of 1986 requirements with respect to recycling and processing of residues were also set. Additionally, various technological and organizational-technical requirements were imposed which were relevant to the non-ferrous metal industry, in order to decrease dust and heavy metal emissions. One reason for the replacement of the older plants mentioned above were the rising costs of necessary pollution control.

Although, even before then, authorization had been required for new plants, since 1960 new federal legislation enabled the authorities to command technically feasible and economically reasonable orders for existing plants.

Other reasons for the improvement in technologies - in addition to legally imposed requirements - were the enterprises' aims of reducing costs[37] and increasing returns, as well as a rising public interest in environmental protection. In order to reduce the costs of raw materials, energy and waste disposal, technologies were installed that reduced energy inputs and that allowed the processing of secondary materials and production residues. In order to further increase returns enterprises opened plants for the production of by-products.

Apart from general financial support available for investment in environmental technologies, consisting, in the first place, of tax allowances, financial support for the development and start-up of the QSL-plant at Berzelius was paid by the Northrhine-Westfalia and West-Germany governments.

Development of Immissions and Remaining Environmental Problems

Measurements of immissions in 1988 showed that there were, in general, very low deposits of dust and fly dust, as well as of the heavy metal compounds they contained. Standards for dust deposits and the heavy metals they contain, as set in the `technical direction air' 1986 were only exceeded in few industrial areas, mainly around Duisburg and Datteln. A further result of this investigation was that, since 1986, immissions declined throughout the whole Ruhr Area.

The current problems of the non-ferrous metal industry are more the by-products than the emissions from furnaces. These by-products consist of not easily soluble compounds, such as hematite produced by electrolyses. This leads to a medial shift in the problem which can be seen as having both positive and negative effects. Residues not easily mobilized may be considered as advantageous over easily mobilized dust emissions which contain heavy metals.

Problems with emissions from flotation sites do not occur in Northrhine-Westfalia, as there is no ore mining. Raw materials are either imported as ore concentrates or consist of secondary materials.

5.2. Outlook for Further Research

In summary, the question whether progress in the sense of an improvement of industrial metabolism - i.e. a successful connection in solving economic and environmental requirements - was succeeded, can not yet be definitively answered.

On the one hand there was an increase in the re-use of production residues and an increasing trend towards the closing of economic material circles, as well as the production of by-products -

---

[37] The necessity of reducing costs was also due to changes in the economic framework, such as a decline in metal prices and rising energy costs in the course of the oil crises.

leading to input changes, a reduction in waste, and increases in returns - over the time period investigated. Previously only end-of-pipe technologies had been used to control air pollution. The modernization of processes partly decreased costs also. It was expected that for example the QSL process at Berzelius Stolberg would reduce running costs and investment costs (by 30 to 40%) compared with the conventional process.

At the same time there are, however, suspicions, that these new process technologies generate more complex substances, whose impact on the environment and health is more difficult to assess. Also the question, of whether an increase in secondary non-ferrous metal production reduces environmental problems, i.e. whether secondary materials are less contaminated with heavy metals than primary metal ores, could not be finally answered. These are questions that could not be sufficiently investigated in this study and which should be subject to further research.

Acknowledgements

I would like to thank Dr. Jürgen Blazejczak for his many useful comments during this study.

References:

ABMS: Non-Ferrous Metal Data. Several volumes. American Bureau of Metal Statistics Inc. New York.

ABMS 1971: Year book of the American Bureau of Metal Statistics. Fiftieth Annual Issue for the year 1970. American Bureau of Metal Statistics. New York.

Anyadike, N. 8 March 1990: Ruhr-Zink Plant Expansion on Schedule. In: Metal Bulletin. 8.3.90.

Anyadike, N. 15. March 1990: Berzelius QSL Unit Set for June Opening. Scrap and Secondary Metals. In: Metal Bulletin. 15.3.90.

Bayer, K. 1960: 150 Jahre deutsche Zinkhüttenindustrie. In: Metall, Heft 8, 14. Jahrgang. August 1960.

BddW 1982: Bleiverhüttung umweltfreundlicher und billiger. Eine Demonstrationsanlage in Duisburg arbeitet bereits. In: Blick durch die Wirtschaft, 1.3.1982.

Blazejczak, J. 1995: Dealing with Heavy Metal Pollution in Katowice - Learning from the Ruhr Area Experience. Deutsches Institut für Wirtschaftsforschung. Berlin.

Blazejczak, J. 1995: Rhine/Black Triangle Policy Comparison Workshop. March 2-3, 1995. Workshop Report. International Institute for Applied Systems Analysis. Laxenburg/Austria.

Boesler, K.-A,/Breuer, H. 1989: Standortrisiken und Standortbedeutung der Nichteisen-Metallhütten in der Bundesrepublik Deutschland. Wechselwirkungen zwischen Ressortpolitik, Industriestruktur und Raum. Forschungen zur deutschen Landeskunde, Band 233. Trier.

Chem. Ind. 1982: Unternehmen im Spiegel. MG: Zinkkooperation mit Australien. In: Chemische Industrie XXXIV/November 1982.

Clark, R. 1986: Lead-Zinc Producer Urges Caution. In: MBM, June 1986.

De Bruyn, S./Schucht, S. 1996: Industrial Transformation and Development of Heavy Metal Emissions in Northrhine-Westfalia: Decomposition and Material Flow Analysis. Working Paper. WP-96-8. International Institute for Applied Systems Analysis. Laxenburg/Austria.

Dobner, R.F./Schwill, M. 1995: Kupferraffination: Erweiterung und Modernisierung einer konventionellen Elektrolyse. In: Erzmetall 4/95.

Ehrenberg, D. 1986: Production Costs keep Ruhr-Zink on its toes. In: Zinc & Alloys Pty. Ltd. Zinc and Galvanizing. A Supplement to Metal Bulletin Monthly. January 1986. Sydney/Australia.

E&MJ 1981: Sherritt Commercializes Zinc Pressure Leaching. E&MJ December 1981.

E&MJ 1983: Lurgi Campaigns. QSL Lead Smelting in 30,000-MT/YR Prototype Module at Berzelius. E&MJ July 1983.

Fischer, P. 1982: Zum Entwicklungsstand des QSL-Verfahrens. In: Metall. 36. Jahrgang, Heft 3, März 1982.

Gebhardt, A./Knörndel, K.D. 1977: NE-Metallindustrie. ifo-Institut für Wirtschaftsforschung. Struktur und Wachstum. Reihe Industrie, Heft 28. Berlin.

Gerberding, A./Harms, U. 1976: Verwendung und Rückgewinnung von Blei und Zink in der Bundesrepublik Deutschland. In: Metall, 30. Jahrgang, Heft 12.

Jahrbuch 1995: Jahrbuch 1995. Bergbau, Erdöl und Erdgas, Petrochemie, Elektrizität, Umweltschutz. Hrsg.: C. Brecht et al. Essen.

Klepper, G./Michaelis, P./Mahlau, G. 1995: Industrial Metabolism. A Case Study of the Economics of Cadmium Control. Kieler Studien. Hrsg.: H. Siebert. Institut für Weltwirtschaft an der Universität Kiel. Tübingen.

Krol, W./Steil, H.-U. 1987: Auswirkungen der Umweltschutzpolitik auf die deutsche NE-Metallindustrie. In: Metall, 41. Jahrgang, Heft 9. Duisburg.

LDS: Statistisches Jahrbuch Nordrhein-Westfalen. Diverse Jahrgänge. Landesamt für Datenverarbeitung und Statistik Nordrhein-Westfalen. Düsseldorf.

Maczek, H. 1986: Custom Smelting - a Vulnerable Balancing Act. In: Metal Bulletin. Monthly Supplement, January 1986.

MAGS 1977: Luftreinhalteplan Ruhrgebiet West 1978-1982. Duisburg - Oberhausen - Mülheim. Ministerium für Arbeit, Gesundheit und Soziales des Landes Nordrhein-Westfalen. Düsseldorf.

MAGS 1978: Luftreinhalteplan Ruhrgebiet Ost 1979-1983. Dortmund. Ministerium für Arbeit, Gesundheit und Soziales des Landes Nordrhein-Westfalen. Düsseldorf.

MAGS 1980: Luftreinhalteplan Ruhrgebiet Mitte 1980-1984. Ministerium für Arbeit, Gesundheit und Soziales des Landes Nordrhein-Westfalen. Düsseldorf.

MAGS 1985: Luftreinhalteplan Ruhrgebiet West. 1. Fortschreibung 1984-1988. Ministerium für Arbeit, Gesundheit und Soziales des Landes Nordrhein-Westfalen. Düsseldorf.

Matzke, U. 1988. Die emissionsarme Metallhütte. Luftreinhaltung. In: Umwelt 3/88.

Metal Bulletin 1993: Non-Ferrous Metal Works of the World. Sixth Edition. Published by Metal Bulletin Books Ltd. Surrey/England.

Metal Bulletin 1982: Non-Ferrous Metal Works of the World. Third Edition. Published by Metal Bulletin Books Ltd. Surrey/England.

Metal Bulletin Ltd. 1978: Cadmium. Edited Proceedings. Cadmium Conference. London.

Metall 1968: Neue Zinkelektrolyse in Datteln vor Produktionsbeginn. In: Metall. 22. Jahrgang, August 1968, Heft 8.

Meyer 1971: Meyers Handbuch über Technik. 2. Auflage. Hrsg.: Fachredaktion Technik des Bibliographischen Instituts. Mannheim.

Müller-Ohlsen, L. 1981: Die Weltmetallwirtschaft im industriellen Entwicklungsprozeß. Kieler Studien 165. Hrsg.: H. Giersch. Institut für Weltwirtschaft an der Universität Kiel. Tübingen.

MURL 1989: Luftreinhaltung in Nordrhein-Westfalen. Eine Erfolgsbilanz der Luftreinhalteplanung 1975-1988. Bilanzbericht. Minister für Umwelt, Raumordnung und Landwirtschaft des Landes Nordrhein-Westfalen. Düsseldorf.

MURL 1994: Altanlagensanierung nach Nr. 4 der Technischen Anleitung zur Reinhaltung der Luft - TA Luft vom 27. Februar 1986. Abschlußbericht der Koordinierungsstelle TA Luft. Ministerium für Umwelt, Raumordnung und Landwirtschaft des Landes Nordrhein-Westfalen. Düsseldorf.

Oberbeckmann, F.-K. 1980: 75 Jahre Berzelius. 1905-1980 Berzelius. Hrsg.: Vorstand der Metallgesellschaft AG. Metallgesellschaft AG. Frankfurt/Main.

OECD 1994: Mining and Non-Ferrous Metals Policies of OECD Countries. OECD Documents. Organization for Economic Co-operation and Development. Paris.

Piret, N.L. 1995: Technisch-wirtschaftliche Gegenüberstellung moderner Verwertungsverfahren von Zinkelektrolyserückständen. In: Erzmetall 8/95. GDMB.

Röseler, V. 1992: Das Ziel heißt: Rückstandslose Zinkproduktion. Die Ruhr-Zink GmbH, Datteln. Metall Portrait. In: Metall, Heft 9. 46. Jahrgang. September 1992.

Saßmannshausen, G. 1982: Perspektiven und Aspekte der Rohstoffversorgung in der Nichteisen-Metallindustrie. In: A.v. Bülow et al. Energie- und Rohstoffpolitik. Probleme, Trends und Perspektiven in einer sich wandelnden Weltwirtschaft. Bonn.

Schmidt, M. 1987: Verschärfte Umweltauflagen werden eingehalten. Bleiverhüttung/QSL-Verfahren senkt Betriebskosten/Investitionen deutlich niedriger als bei Standartverfahren. In: Handelsblatt, Nr. 172, 9.9.1987.

Schucht, S. 1993: Ökologische Aspekte des Strukturwandels im Bergbau und Verarbeitenden Gewerbe von Nordrhein-Westfalen. Diplomarbeit. Forschungsstelle für Umweltpolitik. Berlin.

StaBu FS19: Statistisches Bundesamt. Fachserie 19, Reihe 3. Umweltschutzinvestitionen der NE-Metallerzeugung und NE-Halbzeugwerke. Diverse Jahrgänge. Stuttgart.

StaBu: Statistisches Jahrbuch für die Bundesrepublik Deutschland. Diverse Jahrgänge. Statistisches Bundesamt. Stuttgart.

StaLa: Statistisches Jahrbuch Nordrhein-Westfalen. Diverse Jahrgänge. Statistisches Landesamt Nordrhein-Westfalen. Düsseldorf.

Steil, H.-U. 1993: Der Einfluß gesetzlicher Umweltschutzvorgaben auf das Recycling metallhaltiger Rückstände. In: Metall, 47. Jahrgang, Heft 5. Duisburg.

Stigliani, W.M./Anderberg, S. 1992: Industrial Metabolism at the Regional Level: The Rhine Basin. WP-92-10. International Institute for Applied Systems Analysis. Laxenburg/Austria.

Stigliani, W.M./Jaffé, P.R./Anderberg, S. 1993: Pollution in the Rhine Basin. In: Environmental Science & Technology. Vol. 27, No. 5, pp. 786-793.

TA Luft 1964: Technische Anleitung zur Reinhaltung der Luft. Der Bundesminister für Gesundheitswesen. Hrsg.: Bundesministerium des Inneren. Bonn.

TA Luft 1974: Technische Anleitung zur Reinhaltung der Luft. Erläuterte Ausgabe mit einer Einführung vom Bundesminister des Innern Prof. Dr. Werner Maihofer. Köln.

TA Luft 1983: Technische Anleitung zur Reinhaltung der Luft. Erste allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz. Vom 23. Februar 1983. Texte des Umweltbundesamtes. Berlin.

TA Luft 1986: Technische Anleitung zur Reinhaltung der Luft. Erste allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz. Vom 27. Februar 1986. Köln.

Umweltministerium 1986: Luftreinhalteplan Ruhrgebiet Ost. 1. Fortschreibung 1986-1990. Minister für Umwelt, Raumordnung und Landwirtschaft des Landes Nordrhein-Westfalen. Düsseldorf.

U.S. Bureau of Mines 1992: Metal Prices in the United States through 1991. By the Branch of Metals and Branch of Industrial Minerals. U.S. Bureau of Mines. The Minerals Source.

Vennen, H. 1991: Schadstoff bleibt in der Hütte. QSL-Verfahren reduziert die Emissionen von Blei, Zink, Cadmium, Arsen und Schwefeldioxid. In: VDI-Nachrichten, Nr. 3, 18. Januar 1991.

Wettig, E. 1980: Erzeugung und Verarbeitung von NE-Metallen in der Bundesrepublik Deutschland. Standorte und Entwicklungstendenzen. Stuttgart.

ANNEX I: LEGAL FRAMEWORK FOR AIR POLLUTION CONTROL

A. `Technical Directions Air'

A.1. Further Information on Organizational-Technical Measures

In order to reduce dust emissions the following organizational-technical measures are required by *TA Luft 1974 and 1983*:

In the conveying, sorting, racking or similar treatment of dusty comminution materials, the dust containing waste gases shall be collected and fed to dedusting systems. Facilities for producing dust goods with a maximum diameter of 5 mm shall be set up in enclosed areas if the escape of dust is not prevented by complete encapsulation or equivalent measures. Dusty ground goods with a maximum diameter of 2 mm shall be transported in closed conveying facilities and stored in closed containers or areas if moisture corresponding to a mass content of at least 10% water is not continually maintained on the surface. Decanting and packaging systems for these ground goods shall be dust tight.

When dusty bulk goods are stored in the open, measures shall be taken to prevent dust emissions, e.g. by establishing overgrown earth embankments, windbreak plantings or hedges, by encapsulating belt conveyors or other transport systems, by continually adjusting discharge height at discharge and transfer points to the changing height of the pile, by covering the surface, e.g. with mats or large-grained material, by consolidation with binders or, in the case of moist bulk goods, by continual maintenance of moisture level corresponding to a mass content of 10% water on the surface of the pile. If the open storage of dusty bulk goods can result in emissions of materials of class 1 (to which lead and cadmium belong) open storage shall only be permitted if dust emissions are effectively prevented by coverage of the surface.

Closed transport systems shall be used in the elimination of dusty combustion and production residues. If these residues are stored in the open, the above mentioned measures shall apply correspondingly. Surfaces of finished piles shall be planted immediately if possible.

If it is to be expected that dust immissions will result from the use of roadways, the roadway shall be given a cover of bituminous roadbuilding materials, concrete or equivalent material in the vicinity of the facility and cleaned regularly or treated effectively with dust binders.

Dust emissions which might result from the emptying of filter systems shall be prevented by drawing off the dusts into closed containers or moistening them at the removal points.

A.2. Further Information on Special Requirements for Facilities

Special requirements were imposed on facilities producing unrefined non-ferrous metals:

Waste-gases with an SO_2 content of 2% by volume or more shall be fed to a utilizing system. Special values for SO_2 emissions, as well as for dust emissions stemming from lead smelting facilities are imposed. Technologies of the facilities and means for reducing dust and gaseous emissions from lead and copper refineries are presented in the VDI-guidelines[38] VDI 2285 (March 1974), VDI 2102 (October 1966) and VDI 2287 (July 1963) [TA Luft 1974; TA Luft 1983].

As a special requirement imposed for foundries for non-ferrous metals, dust-bearing waste gases shall be collected and fed to filtering-systems and a special value is set for dust emissions in waste gas [TA Luft 1974; TA Luft 1983].

B. Clean Air Planning in Northrhine-Westfalia

B.1. Immission Standards According to `Technical Direction Air' 1986

Table B.1.

Immission Standards According to TA Luft 1986				
	Immission Standard I (1)		Immission Standard II (2)	
Dust deposit	0,35	g/(m²*d)	0,65	g/(m²*d)
- contained lead	0,25	mg/(m²*d)		
- contained cadmium	5	µg/(m²*d)		
Fly dust deposit	0,15	mg/m³	0,3	mg/m³
- contained lead compounds	2	µg/m³		
- contained cadmium compounds	0,04	µg/m³		

(1) Values set for long term effects.
(2) Values set for short term effects.
Sources: MURL 1989; TA Luft 1983.

B.2. Further Information on the Development of Immissions

In 1988 the immission standard I for *dust deposits* was only exceeded in the areas around Duisburg and Köln. The immission standard II was also exceeded in areas in the Ruhr Area East and the Rhine Area Centre.

Exceeded immission standards for *lead contained in dust deposits* were, above all, found in the Ruhr Area West (in the area of Duisburg), but also in the Ruhr Area Centre and the Rhine Area South. In 1982 the immissions in the Ruhr Area West were twice as high as in the other areas of Northrhine-Westfalia. While in other areas the immissions rose between 1984 and 1985, there was a steady decline in the Ruhr Area West. Since 1986 there has been a decline of immissions in all areas, still being most distinct in the Ruhr Area West.

---

[38] Guidelines of the commission "Reinhaltung der Luft im VDI und DIN". Association of German Engineers (Verein Deutscher Ingenieure).

Immissions of *cadmium contained in dust deposits* are distinctly lower than those of lead. They exceed the standards again mainly in the Ruhr Area West (around Duisburg), but also in the Rhine Area South and in the Ruhr Area East (around Datteln). In the Ruhr Area immissions grew between 1983 and 1984. Since 1986 there has been a decline in immissions in all areas [MURL 1989].

Fly dust deposits declined between 1968 and 1988. *Fly dust deposits containing lead compounds* declined considerably between 1974 and 1988[39], the highest reductions, however, were to be found in the Ruhr Area [MURL 1989]. Between 1974 and 1988 *fly dust deposits containing cadmium compounds* declined by about 80% in the Ruhr Area [MURL 1989].

[39] The most marked reductions were achieved in the period up until 1981.

ANNEX II: NF-METAL PRODUCTION TECHNOLOGIES

A. Zinc Production

A.1. Hydrometallurgical/Electrolytic Process

A modern hydrometallurgical process consists of 6 production steps [Röseler 1992]:

1) Roasting of zinc concentrates, leading to residues of sulphuric acid and gypsum,
2) leaching, requiring a lot of sulphuric acid to release the zinc, leading to gas emissions, a further residue is a zinc-solution, containing iron,

   Using the Sherritt-Gordon Process, step one and two are replaced by a direct leaching process, leading to the production of elemental sulphur.

3) reprocessing of residues, producing a lead-silver concentrate and the iron residues geothite or jarosite,
4) leach purification leading to copper cement and cadmium, which can be directly processed into cadmium metal, and a zinc solution which is the material used in the zinc electrolytic process,
5) zinc electrolysis, producing zinc,
6) a smelting process, producing zinc products with a purity of almost 100%.

A.2. Jarosite Process

A considerable part of the zinc is bound in zinc ferrite and therefore has to be dissolved by a leaching process. The Jarosite process consists of a pressure leaching process aimed at zinc recovery from leach residues with a high ferritic content, which stem from electrolytic refineries. It was developed at the end of the 60's. Previously there had been no technology to dissolve iron from the solution [Monthly Bulletin April 1971; Piret 1995].

During the roasting of zinc sulphide concentrates a portion of the zinc reacts with any iron that is present to form zinc ferrite. Under usual leaching conditions in electrolytic plants very little of this ferrite is dissolved and goes into the plant residues. In the Jarosite process, ferric iron is precipitated from a slightly acidic solutions as a crystalline double sulphate belonging to the jarosite group [Monthly Bulletin April 1971].

Advantages of precipitating iron as a jarosite compound are [Monthly Bulletin April 1971]:

- precipitates are crystalline solids which can be thickened, filtered and washed free of the zinc-bearing solutions,
- the amount of acid liberated is much less than if the oxide or hydroxide is produced (hence the neutralising agent needs are minimized),
- loss of acid soluble zinc in the precipitate is negligible,
- in zinc plants, because a built-up of sulphate tends to occur, precipitation of jarosites containing combined sulphate is a convenient method of sulphate control.

The Jarosite process needs to run at about 95°C. For every tonne of zinc produced about 900 kg of jarosite is produced [Ehrenberg 1986]. The iron content in the jarosite residue is about 27% to 30%, the zinc extraction rate is about 94% [Röseler 1992]. Jarosite must be carefully disposed of [Anyadike 8th March 1990].

A.3. Hematite Process

The Hematite process has the same aims as the Jarosite process. While the costs of installing and operating are higher for the Hematite process than for the Jarosite process - the sytem needs to run at about 200°C - it also has some advantages over the Jarosite process and is thought to improve cost effectiveness [Ehrenberg 1986]:

- it raises the zinc extraction rates to 98%,
- it causes less residues than the Jarosite process (for every tonne of zinc produced about 300 to 400 kg of hematite is produced),
- the hematite has an iron content of 55 to 62% which makes it a saleable item.

Both, the Jarosite as well as the Hematite process, have the disadvantage of a high contamination of the iron residues with heavy metals [Piret 1995]. However, the Hematite process causes considerably less environmental problems than the Jarosite process.

A.4. Sherritt-Gordon Process

The Sherritt-Gordon process consists of oxidative pressure leaching of zinc concentrates and replaces the older roast-leach section. This zinc producing process makes use of the Sherritt pressure leaching technology first developed in the 1950's [E&MJ 1981; Röseler 1992].

In processing zinc concentrates, a four-compartment autoclave is used to convert zinc sulphides directly to zinc sulphate solution and elemental sulphur. The process is based on the fact that, at elevated temperatures and pressures, zinc sulphide, lead sulphide, and some iron sulphide minerals react with oxygen and sulphuric acid to form simple sulphates, elemental sulphur, and water [E&MJ 1981].

Subsequent solution purification and electrolysis are the same as previously used. Because the process produces elemental sulphur, rather than sulphur dioxide gas, acid plants and smoke stacks are not required, and air quality and plant working conditions are greatly improved.

Further advantages over conventional plants are [E&MJ 1981]:

- the process requires less labour and less building space,
- it can be applied to low-grade concentrates, with very high recoveries (up to 98%) if the process design provides adequate retention time,
- the process tolerates more lead in the concentrate, and the lead can be recovered as a by-product.

B. Lead Production

B.1. Lead Refining - Conventional Process

Conventional lead refining - in so far as it relates to sulphidic ores[40] - consists of a two stages process. In the first stage the concentrate is roasted[41] and at the same time sintered. In the second step the sinter is smelted in a shaftfurnace and, with help of coke, the lead content is reduced to metal. This technology leads to a considerable amount of exhaust gas and - due to the sintering - to dust emissions [BddW 1982].

Possibilities for technological improvements of this process are more or less exhausted. Earlier attempts to develop a one stage lead refining process failed as the injection of oxygen into the oven from above led to temperatures of about 1500°C and damaged the oven brickwork [BddW 1982].

B.2. QSL Process

The one stage QSL process avoids these difficulties. In the oxidation zone oxygen is blown through vertical, gas-cooled injectors into the hot melt at about 1100°C. Here the ore concentrate, which contains lead and sulphur dissolves continuously. At the same time the sulphur is oxidized[42] and separated from

---

[40] Sulphidic ores are ores in which the lead is bound to sulphur. This holds true for the majority of the world's lead ore production.

[41] I.e. oxidised using oxygen and de-sulphured.

[42] By adding oxygen the sulphur reacts to form sulphur dioxide.

the metallic lead. This roasting process produces low-sulphur lead, lead-rich slag, sulphur dioxide and a small amount of flue dust [BddW 1982; Vennen 1991; E&MJ 1983].

In the reduction zone, pulverized coal is injected by means of carrier gas, and the temperature is raised to about 1,200°C. The lead oxide contained in the slag is reduced to metallic lead [Vennen 1991; E&MJ 1983].

In Stolberg the lead is cleaned of impurities, e.g. copper, arsenic, tin and silver and the lead content of the remaining slag is reduced to 1%. The slag flows continuously into a granulation launder [E&MJ 1983] and can be used in road construction. While residues arising from lead refining used to be only partially re-used, they can now be recycled to a great extent [Vennen 1991]. Examples of by-products are sulphuric acid, cadmium carbonate, arsenious trioxide and silver. The energy from the hot exhaust gas (the process runs at about 1000°C) is used to generate electricity.

Emissions are reduced in the following ways: As the lead is produced in a single step, the exhaust gas contains higher amounts of sulphur dioxide and can therefore be processed more easily into sulphuric acid [BddW 1982]; the SO_2-rich off-gas is cleaned in a hot electro-percipitator [E&MJ 1983]. The dust intensive sintering, necessary for the older process, is no longer required. Flue dust which is still produced is separated with help of electro filters. It was expected that sulphur dioxide emissions into the air would be reduced by 93%, and dust emissions to 80% compared with the conventional process. Furthermore, the investment costs of this process are 30 to 40% lower than of the conventional process. The running costs are also lower [BddW 1982].

Advantages of the process are [E&MJ 1983]:

- the process is continuous and takes place in a single reactor,
- the lead and sulphur contents of the charge are not restricted, so a wide range of concentrates and lead containing materials can be treated directly without dilution of returns,
- the total mass of solids handled in QSL processing is considerably less than in conventional smelting,
- to prevent lead from becoming airborne, process materials are moistened and pelletized wherever possible,
- handling of dry materials is restricted to pneumatic transport of flue dust in sealed conveyors; problematic operations such as crushing and screening of lead-bearing materials are excluded,
- the length of transport lines and the number of material transfer points are minimized,
- a high degree of automation is possible for important operational components such as tuyeres and tap holes,

- heats of oxidation of the sulphides are utilized in smelting the charge,
- use of oxygen results in a considerably reduced volume of off-gas. All this off-gas derives from a single source,
- use of oxygen also considerably lowers the fossil fuel requirement, and low quality coal can be used as fuel,
- any sulphur contained in the raw materials or in the fuel is readily collected as a concentrated SO_2 off-gas that can be converted to sulphuric acid with a high rate of gas recovery,
- off-gas temperatures of about 1,100 to 1,200°C permit waste heat recovery (if waste heat is recovered and re-used the total electricity consumption of an QSL plant, including the oxygen plant, would be of the same order of magnitude as that of a conventional smelter),
- capital and labour costs are lower than for conventional smelters.

C. Zinc/Lead Production

C.1. Production of Zinc

Because zinc in concentrates is bound to sulphur it must first be seperated from the sulphur in a roasting or sintering process. The intermediate products containing zinc or zinc oxide have then to be cleaned of impurities, e.g. lead, and to be processed into zinc oxide [Meyer 1971]. The next production step is the reduction of zinc oxide to zinc metal.

C.2. Pyrometallurgical/Thermic Process

C.2.1. Intermitted Retort Process

In retort furnaces zinc oxide and coal are heated and the zinc is condensed. By-products are carbon monoxide, used for external heating of the retort furnace, and ash [Meyer 1971].

C.2.2. ISF Process

The ISF-process belongs to the group of thermic processes, using electricity as energy source for zinc production. In the IS-furnaces zinc is reduced and, at the same time, the lead contained is recovered as crude lead. This process uses a condenser in which the zinc containing gases are cooled and condensed very quickly by adding drops of lead. This leads to a zinc-lead-melt which is removed from the condenser and cooled in order to seperate the zinc and lead. The lead is re-used for condensation. The zinc has to be further refined [Meyer 1971].

C.3. New Jersey Process

The New Jersey process is a refining process producing high quality zinc. At about 1200°C the metal is seperated into lead and distilled zinc and cadmium. This cadmium-zinc mixture is then seperated by distillation of the cadmium at about 1400°C. The cadmium dust is collected to recover cadmium. The remaining zinc has a quality of almost 100% [Meyer 1971].

C.4. Comparison Between Electrothermic and Electrolytic Processes

Unlike zinc electrolytic processes, pyrometallurgical smelters can handle not only clean zinc concentrates but also complex materials, mixed lead-zinc concentrates and secondary oxides [Maczek 1986].

Operating cost comparisons between zinc production with the electrolytic process and zinc-lead production with the ISF process [Maczek 1986] showed that the operating cost of the ISF is about 10% higher, the difference mainly arising from higher labour costs, which have to be off-set against factors such as lower-cost raw materials in order to achieve profitable operation and to be competitive.

The Imperial Smelting Furnace at Duisburg, a 100% custom smelter[43], can treat virtually all types of raw materials which are available. Selection of the feed is, therefore, one of the fundamental factors for economical operation [Maczek 1986]. Material assessment calculation has to be based on metallurgical parameters, cost prices (raw materials, labour, maintenance, energy) and metal price quotations.

[43] A custom smelter is forced to keep considerable stocks of raw and intermediate materials, as well as metal.