MARCH 1997 ECN-C--97-019

THE BASIC METAL INDUSTRY AND ITS ENERGY USE

Prospects for the Dutch energy intensive industry

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Framework of the study

This report is a result of the project 'The Future of the Dutch Energy Intensive Industry', ECN project number 7.7089.

Abstract

This report discusses the current state and the future of the Dutch basic metal industry. The steel industry and the aluminium industry are discussed in detail. First their current energy use, the technology and their product markets are analysed. The competitiveness of Dutch and Western European producers is discussed. Main technological developments and other key issues (especially future CO_2 policies) are analysed. Based on this analysis, scenarios are developed for the energy use in the basic metal industry for the period 2000-2020.

CONTENT

SUMMARY

This study analyses the long term perspectives for the Dutch steel and aluminium industry. Both metals appear to have their own properties and markets, steel being the cheaper constructive bulk material while aluminium is typically applied where weight reduction, corrosion resistance and easier processing characteristics are valued. Comparison of steel and aluminium shows clearly two metals in a different phase of their economic life cycle. They differ in their physical production volume, their technological development and their importance for the economy.

Steel is a mature metal with a declining production volume within Western Europe during the last two decades. The material is produced by a large number of companies in Europe with a predominantly national character. Because of the stiff competition and the stabilising demand in Western Europe, the profit margin is small. Transportation costs are a major obstacle for global steel trade for the market segments with low value added. Steel producers aim for vertical integration in order to alleviate price fluctuations and sales problems in bad years. Because of the declining steel consumption, scrap based EAF producers can increase their market share as the post consumer scrap availability increases.

Aluminium is still in the growth phase of the product cycle. Aluminium demand is still increasing, mainly due to substitution of other materials in the transportation sector and other light-weight applications. Because of the increasing demand, there is little incentive to invest to the same extent as for steel in new technology and rapid product innovation. The aluminium production is characterised by an oligopolistic structure within a global market. The high product price (5-10 times the steel price) allows global aluminium trade. Because large amounts of aluminium are stored in long life products and the aluminium demand is still growing, recycling can cover only a part of the aluminium market in the next two to three decades.

Steel

History and present activities

Iron and steel production started in the Netherlands more than 75 years ago. One company, Hoogovens, represents currently 95% of the total steel production. The remaining 5% is produced by Nedstaal. Hoogovens uses the blast furnace technology to produce steel from ores. Nedstaal uses scrap based electric arc furnaces (EAF). Total steel production in the Netherlands has stabilised in the last 25 years.

The blast furnace technology is inherently more energy intensive than the scrap based steel production, because the chemical energy for ore reduction must be added. The blast furnace route at Hoogovens requires approximately 21 GJ per tonne cold rolled sheet, while Nedstaal's EAF production requires approximately 10 GJ per tonne steel wire. Because of

the large fraction of blast furnace steel production, the Dutch iron and steel industry is relatively energy intensive.

Hoogovens has some disadvantages with regard to its product mix. Significant amounts of steel with low added value are still sold in market segments with fierce competition from scrap based products. The company is rapidly changing this position by take-overs of foreign steel rolling and finishing plants. The company recently expanded its steel production capacity after the renovation of one of its two blast furnaces. The current blast furnace technology will be the basis for steel production in the next two decades.

The increasing demand for high quality steel results in increasing energy use for rolling and finishing, but this increased energy use results in an even more rapidly increasing added value. Hoogovens is following the trend towards increased quality through high investments in process and product innovation and the ongoing vertical integration in the steel chain.

While scrap based production abroad has rapidly increased, it has decreased in the Netherlands. Nedstaal cannot compete for bulk steel products and focuses on high quality market niches. The small scale of operations (reduced economies of scale) and the lacking investments in new installations are important reasons for Nedstaal’s low output. Nedstaal is nowadays focusing on wire products like springs and ball bearings and intends to shift away from own EAF steel production to the purchase of steel slabs and billets for further processing. As a consequence, its energy use will decline.

Product market trends

The stabilising steel production in the Netherlands has been related to the decreasing steel demand in all OECD countries. The growth of the global steel demand is currently concentrated in Asia. The European steel industry mainly serves the European market, although Hoogovens exports also significant amounts of steel with high added value (sheet etc.) to North America. The prospects for exports from the Netherlands to Asia seem less promising because of the significant transportation costs and the long delivery periods.

On a European level, steel production is still much higher than steel consumption because of significant net exports. This success makes European producers vulnerable to competition from abroad. If the export declines, serious restructuring of the European industry is required.

Steel production faces strong competition from aluminum and plastics in a number of markets. The main advantages of aluminium and plastics are low specific weight, coupled to acceptable strength and corrosion resistance. Moreover, processing is often easier and cheaper than steel processing. However, the price of the alternative materials is generally higher than the steel price. Steel producers face this competition through quality improvements.

Steel production will increasingly shift to products with high value added. The first reason is that steel will increasingly face competition from other materials. The second reason is that the low quality segment, mainly construction and 'hardware' capital investments, will show lower growth figures than average GDP. The high steel qualities are used in markets with higher growth rates than GDP, like for transportation equipment.

As a consequence of the quality improvement in the last decades, the specific steel consumption for certain applications decreased significantly, for some products even by a factor two. This dematerialisation is not compensated by the increasing product consumption or by development of new steel applications. This dematerialisation trend is one of the reasons for the declining total energy consumption within the steel sector. The decline in physical production does however not imply a decline of the production volume in financial terms, because the quality increase results also in a value increase. This trend of increasing prices is however to some extent balanced by the increasing labour efficiency and capital efficiency.

Dematerialisation is at least as important for the explanation of the declining energy use in the steel industry in the last two decades than increasing energy efficiency and the shift to EAF production. This option is generally not considered as efficiency improvement because it extends beyond the company boundaries. It may be worthwhile to consider the potential for further reduction of energy consumption and CO_2 emissions.

Current technology and energy efficiency

The current state-of-the-art technology for steel making from ores is the blast furnace-BOF route, which can be considered a mature technology. Hoogovens is leading in European with regard to energy efficiency in blast furnace steel production. Coal injection rates are clearly above the European average, which reduces the energy intensive coke production. The recovery rate for residual gases is high and the blast furnaces have been recently completely refurbished. Coupled to a product mix that contains significant amounts of crude products like steel slabs, the specific energy consumption is low.

Nedstaal uses the electric arc furnace (EAF) technology. Its equipment is relatively outdated, and its specific energy use is relatively high compared to other EAF steel producers due to the small scale of operations and the focus on high quality products. However, the EAF technology is still rapidly evolving. Modern, large-scale EAF steel producers (capacity 1 Mt pa or more) are considered a serious challenge for the blast furnace based bulk steel production.

Future technology and energy efficiency for steel production from ore

The iron and steel industry is currently in a process of rapid technological development. The main goal is to substitute the expensive and environmentally problematic coke based blast furnace technology. On the short term, increased coal injection in blast furnaces and increased use of scrap based electric arc furnaces can relief the coke production problem.

On the longer term, the blast furnace iron production route will be replaced by processes based on direct coal use or based on the use of natural gas. The coal based Corex process and gas based direct reduction are proven technologies that are currently applied abroad to produce iron from ores. Hoogovens opts for its own cyclone converter furnace (CCF) technology that could also replace the agglomeration step for the ore fines. This technology is not yet proven on a commercial scale.

An important benefit of these new technologies is more flexibility in production, because the scale of operations is almost an order of magnitude smaller than a conventional blast furnace. The production volume can be much easier adjusted. Such advantages are important in the volatile steel market. Apart from the operational benefits, the environmental impacts like SO_2, NO_x and carbon monoxide emissions will be significantly reduced by these new technologies. The energy efficiency if these new technologies is generally higher than for conventional blast furnace technology because the energy consuming coke making and ore agglomeration steps can be avoided. With regard to the CO_2 emissions per tonne steel, the assessment is not straightforward, because the configuration of the reference energy system (especially the future CO_2 emission related to electricity production) determines to a large extent the impact.

Coal based Corex and CCF generate substantial amounts of energy by-products and can be operated as ‘coal gasifiers’. This type of operation depends however on the existence of markets for the energy products. Hoogovens’ location in IJmuiden has no immediate links with chemical or other industrial complexes, so power generation seems the only feasible application for the residual energy.

In case of substantial CO_2 reduction policies, gas based direct reduced iron (DRI) may become an attractive alternative. DRI can also be imported from abroad. Countries with ample gas and ore availability, can provide comparatively cheap DRI for Dutch steel production.

The combination of DRI and scrap allows the production of steel with very low CO_2 emissions. DRI can overcome scrap availability and scrap quality problems that currently limit global EAF steel production. However, calculations show that the DRI/EAF route is not competitive with the smelting reduction/BOF route in the situation without CO_2 policies. If CO_2 can be removed and stored at costs below 100 NLG/t, smelting reduction technologies remain the most attractive option for primary steel in the case of substantial CO_2 policies. DRI can become attractive if large scale CO_2 storage from smelting reduction processes is not applied. High removal and storage costs (>100 NLG/t) result also in a shift to DRI. In both situations, CCF can also become an important technology because of its low production costs and high energy efficiency.

On the short term, Hoogovens has no plans to switch to alternative iron production technologies, because the two existing blast furnaces will last for at least 10 more years. Timely initiation of this transition seems however recommended in order to solve the operational problems related to new technologies. The current focus on CO_2 emission reduction may also result in increased R&D efforts for CCF. The announced introduction of thin slab casting and strip casting technologies can reduce the energy consumption in the rolling section on the short term, while the production costs are simultaneously reduced.

Recycling and the scrap market

Scrap based EAF steel production is a cost-effective and mature technology to produce steel. EAF technology has environmental benefits: the CO_2 emission is significantly lower than for blast furnace steel technology. The Netherlands are a major scrap exporter. From both viewpoints, scrap based EAF technology seems attractive. However, the scrap availability is limited and scrap prices will rise with increasing international demand. Moreover, Hoogovens, the main Dutch steel producer, has no EAF experience. Nedstaal has insufficient funds to upgrade its current facilities, but the know-how regarding the upgrading exists and the incentives are apparent. The amount of tramp elements in scrap may also pose problems for the higher steel quality market segments, but rigid scrap selection and secondary metallurgy can prevent most quality problems. In conclusion, increased scrap based EAF steel production seems on the short term less likely in the Netherlands due to the institutional problems.

Competitors

Competitors within Europe face largely the same position as Dutch steel producers. A number European steel producers are however significantly larger than Hoogovens. These companies have predominantly national activities; Hoogovens has increasingly the character of a multinational. Hoogovens’ location in IJmuiden where sea-going vessels can board proves to be a significant advantage, because transportation costs for both resources and products are low compared to producers at inland locations. Competition on the Western European steel market from producers that are located outside Europe seems less likely. Increasing quality requirements, increasing labour productivity, high transportation costs and still existing trade barriers prevent major competition from other regions. The exception may be DRI imports from outside Europe. The strong export position of Western Europe (and of Hoogovens) on global markets may on the longer term be challenged by other producers (especially from Asia).

Energy demand forecast

The energy demand forecast for the Dutch iron and steel industry depends on the future production of Hoogovens and the technology that will be applied. Nedstaal is relatively insignificant from an energy consumption point of view. The appearance of a foreign primary steel producer seems less likely and is not considered. Three scenarios are developed. The first scenario is an expansion of Hoogovens in the shrinking European market because of the successful CCF technology, which results in a significant competitive advantage. The coal consumption increases significantly, but the amount of energy by-products increases, too. The second scenario assumes a choice for DRI technology and scrap recycling initiated by policies for substantial CO_2 emission reduction or by failing development of

CCF. DRI allows flexible production of smaller batches with significantly lower CO_2 emissions. The energy consumption decreases and switches from coal to gas and electricity. In the third scenario, a switch to new smelting reduction technologies is not successful and Hoogovens retains blast furnace technology. Shrinking primary steel production in Europe results in a focus of Hoogovens on products with high added value with only one blast furnace. The result is a considerable decline in energy use, coal remains the dominant energy carrier.

Aluminium

History and present activities

Aluminum production in the Netherlands can be divided into primary production from alumina and secondary production from scrap. Primary aluminium is produced by Pechiney and Aldel. Pechiney started its operations in Vlissingen due to the availability of cheap electricity from the nuclear plant in Borssele. The Aldel smelter is owned by Hoogovens. The production started at the beginning of the 70’s due to the availability of cheap gas based electricity. The primary aluminium production has remained more or less on a constant level in the last 25 years. The closure of primary aluminium production in the Netherlands has been forecast in the last decade, but closure plans are only known for the Aldel plant in 2005. The low Dutch electricity prices are one important reason for the ongoing production in the Netherlands. Aluminum recycling increased significantly in the last decade. The Dutch recycling companies seem currently in a better position than the primary aluminium producers. However, further expansion of recycling activities is limited by the availability of aluminium scrap.

Product market trends

The aluminium market is a global market. This fact is for Dutch producers rather a threat than a benefit. Foreign producers can enter the European market, the reverse seems highly improbable. Because the aluminium demand is still rapidly increasing, both within Europe and abroad, new aluminium capacity can be included in the market without long term price decreases. This is shown by the rapid incorporation of the Russian aluminium production capacity that became available in recent years. Aluminium is very gradually gaining a position in the traditional steel markets. Its light weight, corrosion resistance, processing possibilities and comparatively easy recycling will strengthen its position on the long run.

Technology and energy efficiency

Primary aluminium production from bauxite requires more than ten times as much energy as aluminium recycling. The main consumption is related to the electrochemical conversion of alumina (Al_2O_3), to aluminium. The Hall-Héroult electrolysis cell is the current state of the art electrolysis technology. This technology has been steadily improved over the last 100 years. The technology is mature, but gradual improvements of both productivity and environmental performance are still possible.

A new production technology for aluminium from bauxite seems currently not in sight. The only ongoing research in primary aluminium production is aimed at inert anodes and cathodes. Improved electrodes can significantly enhance the energy efficiency. Introduction of inert anode technology can potentially eliminate anode consumption and reduce the electricity consumption. The prospect of successful developments are however still unclear.

Improved technology can however be applied in order to increase aluminium scrap recovery rates, especially with regard to aluminium in municipal solid waste (MSW). This would include improved Eddy Current separation systems and improved recycling technology, because the quality of this waste is low. The impact of such developments on the energy demand of the Dutch aluminium industry is probably limited. Secondary aluminium cannot replace primary production. Scrap availability is insufficient as the increasing aluminium product stock is still a major materials sink.

Competitors

Competing primary aluminium producers are located in countries with low electricity prices. The availability of cheap hydropower in developing countries seems however not sufficient incentive to direct large investments in primary smelters to these locations. The stability of these favourable conditions on the long term is equally important. As electricity markets become more developed and liberated, both in developed and developing regions, extremely low or high electricity prices cannot last. Competition is further reduced by the growth of the aluminium market. Foreign producers will probably primarily focus on the rapidly increasing Asian market. Competitors from surrounding countries face similarly high or even higher electricity prices. Many of these smelters are considerably smaller than the Pechiney smelter in Vlissingen. As a consequence, other European producers seem in a less advantageous position than Pechiney Vlissingen. While the future of Pechiney is still unclear, it has been announced that the primary smelter of Aldel will be closed in 2005. The future role of the Dutch smelters depends ultimately not only on cost prices, but also on the company policies of Pechiney and Hoogovens.

Energy demand forecast

The energy demand for aluminium production in the Netherlands will mainly depend on the future of Pechiney. The potential for increased energy efficiency is limited. If the operation in Vlissingen is prolonged, the electricity demand could rise to approximately 14 PJ_e due to capacity expansion.

1. INTRODUCTION

1.1 Background and purpose

This study results from the project ‘The Future of the Dutch Energy Intensive Industry’. Within this project, future developments in energy intensive industry sectors are analysed. Because these industries are important energy consumers, they determine to a considerable extent the future energy consumption. Recently, a modest economic upswing in the Netherlands in which basic chemicals en basic metals took part, ‘disrupted’ national energy forecasts and CO_2 reduction prospects. Therefore, studying the future of the energy-intensive industry is important for describing and forecasting future national energy consumption.

The general background of industrial allocation and energy consumption is discussed in a separate volume of this study [1]. Also, a sector study was released about the petrochemical industry [2]. This volume focuses on the steel and aluminium industry. These two industries represent the largest part (from an energy point of view) of the basic metal industries. The basic metal industry is the third most important industrial sector from an energy consumption point of view. Table 1.1 lists industrial primary energy consumption.

Table 1.1 *Industrial primary energy and feedstock consumption*[1]

	Energy [PJ/year]	Feedstock [PJ/year]	Total [PJ/year]	[%]
Petrochemicals	160	200	360	31
Refineries	160	-	160	14
Basic metal	107	45	152	13
Fertilizers	53	75	128	11
Food	114	-	114	10
Inorganic chemicals	34	28	62	6
Paper & print	48	-	48	4
Building materials	43	-	43	4
Other	70	20	90	7
Total	801	338	1162	100

[1] Assuming 40% efficiency for electricity production.

Table 1.1 shows that the basic metal industry represents 13% of total industrial energy consumption. The major part of this energy consumption is for steel and aluminium production. Therefore, developments in industrial energy consumption depend on the future of both metal producing industries. In turn, the future of the aluminium and steel industries depends on developments in energy supply. This study analyses factors that are important for the future of the Dutch steel and aluminium industry and their energy use, both absolute levels and composition. Both supply and demand side for both metals and the developments in the next two decades (period 2000-2020) are discussed.

This study will be used as a building block for studies on energy and the environment. These studies include national energy consumption forecasts and scenarios, analyses of energy policy instruments, studies on interactions of energy and the materials system and studies on the evaluation of future R&D activities. Therefore, this study serves no specific policy issue and is intended to discuss all factors that are considered to be important for the future developments within this industrial sector.

Steel and aluminium compete in a number of markets. Both can for example be used for applications like transportation equipment, cladding of buildings, window frames, beverage cans. Other markets are on the other hand reserved for one of both metals: steel tubes, structural steel frames in buildings, aluminium foil. Their competition will be illustrated by a number of case studies in Chapter 3.

While the competition between both metals is often considered important for the future of global steel production, one should keep the different production volumes in mind. The global steel production amounts to 750 Mt, while the global aluminium production amounts to 20 Mt, so global steel production volume (in weight units) is almost 40 times the volume of the global aluminium production. However, the difference is smaller in financial units or in functional units. A financial comparison would result in an global steel industry that has 4 times the size of the global aluminium industry. A comparison of materials services in products (functional units) is complicated, because both metals are not compatible in all applications. Where substitution is possible, aluminium can replace steel with a weight ratio of 0.4-0.8 tonne aluminium per tonne steel. If an average weight ratio is assumed, the global steel production would represent approximately 20 times more functional units.

The competition between both metals is however limited to applications where the light weight, corrosion resistance or easy processing of aluminium are significant advantages. Its higher price makes aluminium not competitive in bulk applications. Its physical characteristics limits aluminium applications where strength requirements are important.

Another interesting comparison for both metals is their different position in their respective economic product life cycle. Steel has already been applied on a large scale for 100 years and seems to meet its market potential limits, while aluminium consumption is still rapidly growing due to its introduction in new markets. The large scale introduction of aluminium started in Europe only after WW II. This different position in the product life cycle compared to steel has consequences for production structures, improvement potentials and the relevance of policy making in certain areas like recycling and R&D strategies.

1.2 Key Questions and method

The following questions concerning the future of the Dutch basic metal industry serve as guideline for the analysis:

- How do the steel and the aluminium industry deal with competitive production abroad? To answer this question, an analysis is made of the most important competing locations, considering energy and other costs.
- Which technological developments are expected in steel and aluminium industries, and how do these affect energy consumption? The potential of new energy sources, new technologies, and their environmental impacts is studied.
- Can a steel and aluminum industry be built on recycling? The possibilities for increased recycling will be examined.
- Which effects do shifts in fuel costs have on the position of the steel and aluminium industry? The effect of energy monopolist policies on the supply side, as well as environmental taxation is dealt with.
- What is the effect of environmental and economic policy strategies regarding the steel and aluminium industry, and what are the strategy options and strategy consequences?
- Which major developments on the market for steel and aluminium products affect the position of the steel and aluminium industry and their energy consumption?

To answer the questions put above, it will be necessary to study the cost structure of the steel and aluminium industry, as well as factors of a less quantitative nature. The Dutch situation will be the reference case. For many issues no univocal data could be found, moreover, crude assumptions had to be made for long term averages in a volatile market. Starting from the national reference situation, comparisons can be made in a systematic way for different settings. These settings include alternative locations with a different energy and raw material supply; expected process technology developments in the next 20 years; substantially higher electricity prices or energy taxes evolving from changes in policies at home or abroad. Naturally these settings can coincide and interact. Therefore, the presented settings and calculations are to be regarded as the initial situation in which a certain development occurs.

Several economic studies have been made for this sector, answering similar questions about competitiveness and sensitivity to price shocks. In the Netherlands, two of these have to be mentioned. The first one is the COB-SER study in 1983. This study analysed the sensitivity of the Dutch industry for price shocks, like the ones that had occurred in the oil crises of the seventies [3]. The second one is the KWW report in 1991, studying the effects of an energy tax on the competitiveness of the industry [4]. Both these studies have analysed current processes and technology to a certain extent, but they were economic by nature, answering economical questions. This present study tries to find new viewpoints by integrating energy and process technology dynamics with the economic picture.

1.3 Structure of the Study

This case study can be divided into an analysis of the current situation (Chapter 2-9) and alternatives for production and energy consumption of the Dutch steel and aluminium industry within their Western European context (Chapter 10-13). Chapter 2 analyses the current aluminium and steel industry production structure and the historical developments. Chapter 3 analyses markets for Dutch aluminium and steel and their competition. Chapter 4 discusses current aluminium production technology. Chapter 5 analyses the aluminium industry economics in the Netherlands in terms of costs and revenues. Chapters 4-5 are followed by a similar analysis for the steel industry in Chapters 6-7. Chapter 8 provides information on institutional factors that influence industrial activities. Chapter 9 discusses global competition for both steel and aluminium with special emphasis on competition for the European market. Chapter 10 analyses potential technology shifts. In Chapter 11, data from the preceding chapters on markets, competition, structure and technology are combined in a comparison of international production structures. This is followed by a sensitivity analysis in Chapter 12. Based on a production volume forecast and the development of the energy intensity of production, future energy consumption of the Dutch steel and aluminium industry is forecast in Chapter 13. Finally, Chapter 14 provides conclusions and policy recommendations.

2. THE PRESENT DUTCH STEEL AND ALUMINIUM INDUSTRY

2.1 System boundaries and statistics

In national statistics, national industry is subdivided into groups of companies with similar main products [5]. The basic metal complex extends however across this standard industrial classification. Table 2.1 shows the subdivision of the aluminium and steel industry and related product sectors.

Table 2.1 *SBI subdivision of the steel and aluminium industry and related sectors [5]*

SBI'93	Sector
Steel	
271	Iron, steel and ferro-alloy production
272	Production of iron and steel tubes
273	Other primary processing of iron and steel
2751	Iron casting
2752	Steel casting
2310	Coke production
28	Metal product manufacturing
3710	Preparations for recycling of metal scrap
Aluminium	
2742	Aluminium production
2753	Light metal casting
28	Metal product manufacturing
3710	Preparations for recycling of metal scrap
3162	Production of other electric equipment (includes anode production)

Energy data are available for SBI'93 code 27, divided into the ferrous basic metal industry and the non-ferrous basic metal industry, including figures on fuel conversions, CHP and non-energetic purposes [6]. Data for the ferrous metal industry are summarized in Table 2.2. Data for the non-ferrous basic metal industry are summarized in Table 2.3. These figures include other non-ferrous metal production processes, e.g. the zinc industry. The electricity use is however predominantly for primary aluminium production. Because of the specific nature of the aluminium and steel industry and their importance from a national point of view, most energy consumption models used for national studies (e.g. by the Central Planning Bureau and ECN Policy Studies) make separate assessments for both industries.

Table 2.2 *Energy balance ferrous basic metal industry, 1994 [7]*

Energy-carrier	Apparent final energy consumption [PJ] 1	Conversions Input CHP [PJ] 2	Conversions Input Other [PJ] 3	Conversions Output CHP [PJ] 4	Conversions Output Other [PJ] 5	Final use Total [PJ] 6=1-2-3+4+5	Final use Non-energetic [PJ]
Coal products	75.93	3.73	31.78	-	31.46	71.87	13.89
Oil products	0.33	0.15	-	-	-	0.18	0.01
Natural gas	12.93	1.17	-	-	-	11.76	-
Electricity	7.21	0.02	-	0.76	-	7.95	-
Steam/hot water	-	-	-	3.50	-	3.50	-
Total fuels	96.40	5.08	31.78	4.26	31.46	95.26	13.90

Table 2.3 *Energy balance non ferrous basic metal industry, 1994 [7]*

Energy-carrier	Apparent final energy consumption [PJ] 1	Conversions Input CHP [PJ] 2	Conversions Input Other [PJ] 3	Conversions Output CHP [PJ] 4	Conversions Output Other [PJ] 5	Final use Total [PJ] 6=1-2-3+4+5	Final use Non-energetic [PJ]
Coal products	0.03	-	-	-	-	0.03	-
Oil products	2.72	-	-	-	-	2.72	2.64
Natural gas	4.18	0.43	-	-	-	3.75	-
Electricity	16.49	-	-	0.05	-	16.54	11.65
Steam/hot water	1.13	-	-	0.29	-	1.42	-
Total fuels	24.66	0.43	-	0.34	-	24.57	14.32

The aluminium industry

The present Dutch aluminium industry can be divided into:
1. primary aluminium smelters (aluminium from bauxite ore)
2. secondary aluminium smelters (aluminium from scrap)
3. anode production
4. the aluminium processing industry.

Aluminium processing industries are not considered in detail, because their energy consumption is relatively small compared to the other three groups of operations. Furthermore, their operations show considerable diversity.

The Dutch aluminium industry consists of two primary smelters:
- Aldel Delfzijl (capacity 97 kt/year)
- Pechiney Vlissingen (capacity 170 kt/year).

8 companies recycle post-consumer waste. The size of secondary smelters is generally one order of magnitude smaller than the size of primary smelters (on average 20 kt per year). Companies in this sector are:
- Alcoa Drunen
- Aldel Delfzijl
- Alumax Kerkrade
- Aluminium Hardenberg
- FHS Dedemsvaart
- Hunter Douglas Rotterdam
- Nedal Utrecht
- Pechiney Vlissingen
- Recyclingbedrijf Oss.

The production of primary aluminium seems to be stabilising, while the production of secondary aluminium is still rapidly growing. This is shown in Figure 2.1: primary aluminium production grew rapidly between 1965 and 1975, but stabilised afterwards or is even slowly decreasing, while secondary production tripled in the period 1984-1994.

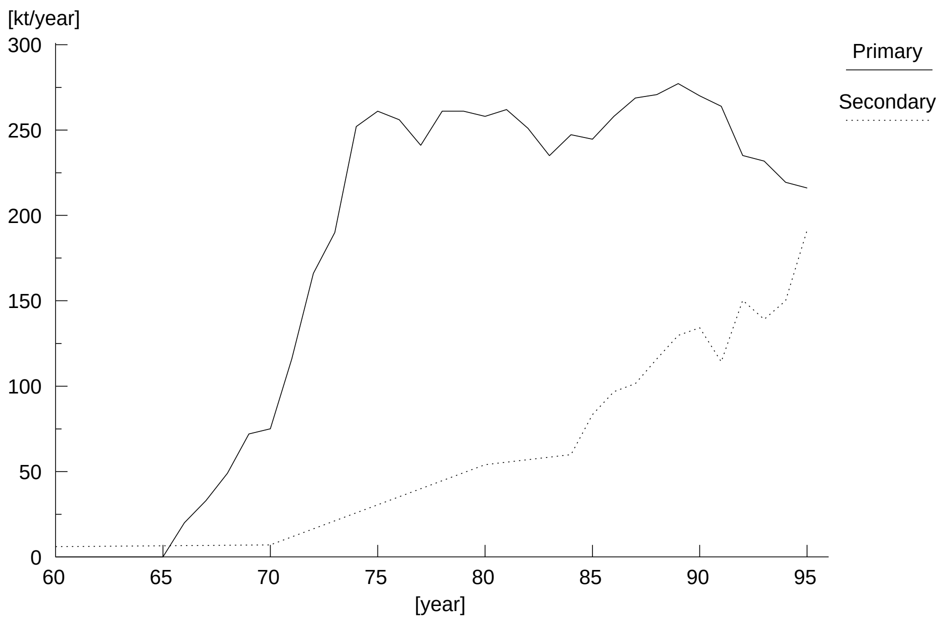

Figure 2.1 *Dutch aluminium production, 1960-1995 [8,9]*

Dutch aluminium production fits well into the general picture of the Dutch materials industries with regard to its international market orientation: a significant part of the Dutch aluminium production is exported. A total of 415 kt primary and secondary aluminium was produced in 1990. The apparent consumption of primary and secondary aluminium was only 232 kt, the remainder (183 kt) was (net) exported.

National markets for aluminium can be characterised by the processes that are used to convert the primary and secondary aluminium ingots. The production amounted in 1990 to 100 kt extrusions, 54 kt rolled products and 13 kt castings (total 167 kt). Extrusions are generally made from primary aluminium, while for castings and rolled products also secondary aluminium is used. Aluminium markets are analysed in more detail in Chapter 3.

Another important energy consumer related to the aluminium industry is the anode production. Anode production (an input for primary aluminium production) takes place at the Pechiney plant in Vlissingen (capacity 120 kt/year) and at the Aluchemie plant in Rotterdam (300 kt/year). A significant part of the anode production is exported. The actual figures are confidential, but it is estimated that 70% of the total anode production is exported.

The steel industry

The present Dutch steel industry can be divided into:

1. Hoogovens blast furnace steel production (production 5.9 Mt pa in 1994)
2. Nedstaal electric arc furnaces (production 0.21 Mt pa, bookyear 1993/1994)
3. steel and iron foundries (>25 companies, production cast iron 0.13 Mt pa)
4. steel processing (production of tubes, wire, etc.).

The third and fourth group will not be considered in the further analysis, because their energy consumption is only a small fraction of the total energy consumption of the steel industry (1.2 PJ primary energy for both ferro and non-ferro foundries and 0.5 PJ for steel processing, respectively) [10,11].

Production trends in the last decade are shown in Figure 2.2. The figure shows the relation between crude iron production and steel production. The ratio between iron and steel production changed over time because materials losses in the iron to steel conversion have been reduced in this period and because the scrap use at Hoogovens has changed. The total Dutch steel production ranged during the last 25 years from 5 to 6 Mt per year, while the recent refurbishing of one Hoogovens blast furnace resulted in a modest increase to 6.4 Mt steel production.

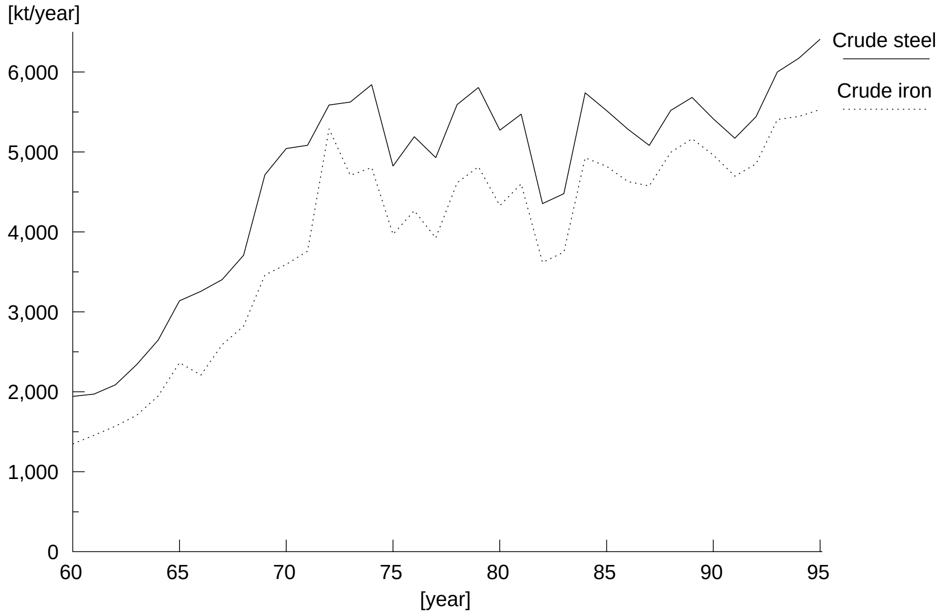

Figure 2.2 *Dutch steel production, 1960-1995 [12]*

Several features indicate a different position of the steel industry in the Netherlands compared to other industrialised countries. The Dutch per capita blast furnace steel production is high, compared to other European countries, while the production from electric arc furnaces (EAF) is low, compared to the blast furnace steel production. The Western European average is approximately 35% EAF production. In the Netherlands, EAF production represents only 5% of total steel production. The EAF steel production is almost stable since 1970. Current plans are to reduce the EAF steel production in the Netherlands even further. A second feature of the Dutch steel industry is its export orientation. The net export of semi-finished and finished steel products amounted to 1.4 Mt in 1993 (23% of the total steel production).

Since its early period, Nedstaal has produced rolled and drawn steel wire from steel scrap. Part of the production is annealed and surface treated. The product is used for springs, fastening materials etc. [13]. Because of the minor significance of Nedstaal from an energy consumption point of view, the analysis of the current situation focuses now on the Hoogovens activities in IJmuiden.

One should emphasize that the multinational Hoogovens has important activities apart from its Dutch steel production site. In the Netherlands, it includes the Aldel aluminium plant (98 kt production capacity). Outside the Netherlands, two primary aluminium smelters are (partially) owned. The first is the primary aluminium smelter in Voerde, Germany (78 kt production capacity, 100% ownership). The company owns also one quarter of the Alouette aluminum smelter in Quebec (which represents 43 kt production capacity). Its total primary aluminum production amounted to 219 kt in 1993, its steel production amounted to 5812 kt. The steel division (excluding the processing and trade division) represents approximately one half of the turnover, the aluminum division (including aluminum processing) one quarter.

Hoogovens IJmuiden consists currently of the following configuration [14]:
- 1 sinter plant
- 1 pellet plant
- 2 coke ovens
- 2 blast furnaces
- 2 basic oxygen furnaces (BOF)
- 1 vacuumpan oven
- 1 hot rolling mill for sheets
- 1 hot rolling mill for bars and wire
- 2 cold rolling mills
- 1 tinplate factory
- 1 zinc coating installation
- 1 paint coating installation.

Figure 2.3 shows the structure of the Hoogovens steel processing units in IJmuiden.

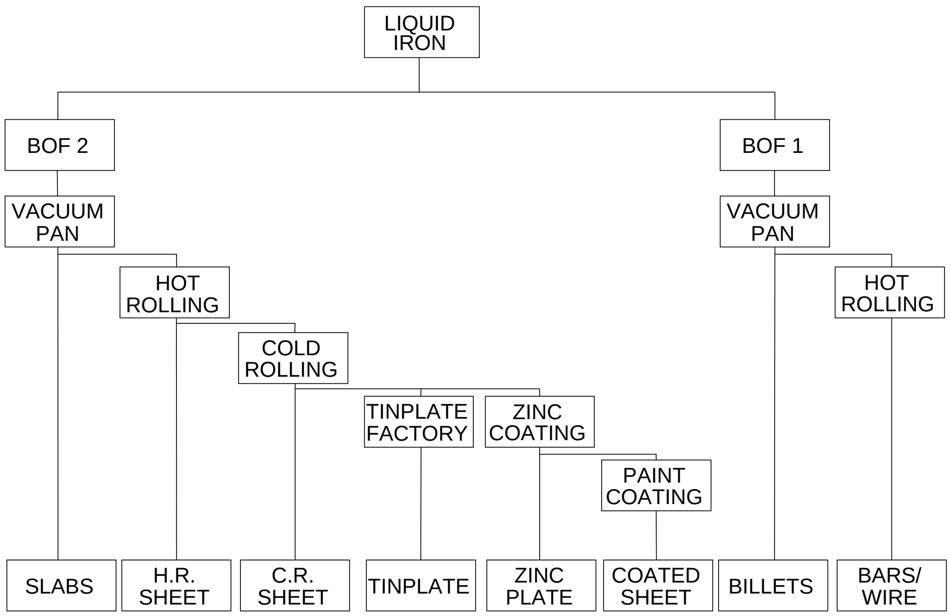

Figure 2.3 *Plant structure of Hoogovens IJmuiden*

The company produces a number of semi-finished products. Its current strategy in the steel sector is more vertical integration into the steel processing chain towards higher value finished products in order to improve its strategic position, increase profit margins and decrease vulnerability to market fluctuations. It remains however to see if this vertical integration will result in an increasing added value per tonne product (and a decreasing energy intensity) for the Dutch steel industry: Hoogovens expanded in recent years through a number of take-overs of steel processing activities outside the Netherlands, like a tin plate rolling mill in Norway and the participation in UGB, a Belgian steel plant with 1.5 Mt steel rolling capacity [15]. This implies no change in the energy intensity of the Dutch activities of Hoogovens!

Coke is produced at the two Hoogovens coke plants and at the coke plant of ACZ de Carbonization in Sluiskil. Hoogovens produces only coke for its own use. ACZ produces for exports. Production capacities are shown in Table 2.4. Hoogovens may close one coke oven, if the plans for increased coal injection are implemented. This is important because one coke oven will approach its end of life around 2005. It is uncertain if permission will be granted for replacement or renovation of the existing coke ovens. The other coke oven can remain in production until the period 2015-2020. These closures interact with the developments in steel production technology and the replacement of the existing blast furnaces that will be discussed in the Chapters 10, 11 and 13.

Table 2.4 *Coke production, 1987 [16]*

Company/Location	[Mt pa]
Hoogovens	1.15
Hoogovens	0.92
ACZ de Carbonisation	0.68
Total	2.75

2.2 Products and processes

Aluminium

Different types of aluminium alloys are used for different types of applications. Table 2.5 provides an overview of the alloy content of different alloy types and their applications. Their physical properties are shown in Appendix A.

Table 2.5 *Aluminium alloys and their applications*

Serial number	Content	Application
1000	Al	Al foils, household appliances, cans
2000	AlCu	Machinery, screws etc.
3000	AlMn	Car outside cladding
5000	AlMg	Car outside cladding
6000	AlMgSi	Car frame, window frames etc.
7000	AlZn	Construction etc.

The content of alloying elements is in the order of 0.1-10%. Table 2.5 lists only the characteristic alloying element of each category. Many alloys contain a number of different alloying elements. The main application for pure aluminium is in household appliances, because pure aluminium does not release toxic compounds. The most important alloy category is Al6000, which is used for transportation and building applications. Because of its high strength and easy processing, Al6000 is attractive for many applications. The different alloys show differences in strength, corrosion resistance and processability. It depends on the application requirements which type is most suited. Often a number of alloys can comply with the product requirements. The materials choice is in such cases determined by costs.

Steel

Ferrous metals are produced in a large number of grades. A first division can be made into cast iron, steel and stainless steel. The first type contains considerable amounts of carbon (>2%), and is a product for iron foundries that are not considered in this report. The last type contains considerable amounts of alloying elements like nickel, chromium or tungsten in concentrations of 5-20%. Its corrosion resistance makes it the best material for certain technical applications. Its price is however ten times higher than the price of conventional steel. Alloyed steel represents approximately 5% of the total steel production. There is no alloyed steel production in the Netherlands. Considering conventional steel, the quality is to a large extent determined by the rolling and heat treatment process. A vast number of steel types can be discerned, based on very small amounts of alloying elements and annealing and rolling operations. They differ in strength, processability, corrosion resistance etcetera. Competition with plastic and aluminium, especially for the transportation market, resulted in a number of new steel qualities in the last two decades. In the process, tensile strength of low alloyed steel qualities increased in the last 20 years by 50%, resulting in similar reductions in materials consumption for applications where the tensile strength is relevant. This development is generally not considered in the evaluation of energy efficiency improvements. It is however one of the explanations for the stabilising Western European steel production, and will be discussed in more detail in Chapter 3.

Table 2.6 shows the product mix for the Hoogovens steel production in 1994. Approximately one third of the total production (reinforcement steel, slabs and billets and hot rolled sheet) was still relatively low value product that can also be made from steel scrap. Hoogovens has difficulties in this market segment because of higher production costs than scrap based EAF producers. The other products fetch a better price because they cannot (yet) be produced competitively from scrap. On the longer run, the production will probably further shift towards such products with high added value (see Chapter 7 for a price comparison of different steel products).

Table 2.6 *Steel industry product mix, 1994 [17]*

Product	[kt pa]
Hot rolled coils	1158.5
Hot rolled sheet	61.8
Hot rolled strips	165.4
Cold rolled coils	1876.0
Cold rolled sheet, galvanised	493.7
Wire	242.4
Concrete reinforcement steel	427.8
Slabs and billets	1873.5
Total	6299.1

2.3 History of production activities

From a materials balance point of view, Europe is often considered a rather closed system. This feature will be discussed in Chapter 3 and Chapter 9. Meanwhile, the characteristics of the steel and industry are discussed in this section from an European point of view.

Figure 2.4 shows the developments in steel and aluminium production for the EU+EFTA region in the period 1960-1990. It is clear that the growth for aluminium was much more spectacular than the growth for steel. Steel production stabilised after 1970. The differences are related to the different position of both metals in their economic product lifecycle. Both materials will be discussed separately to show their different history.

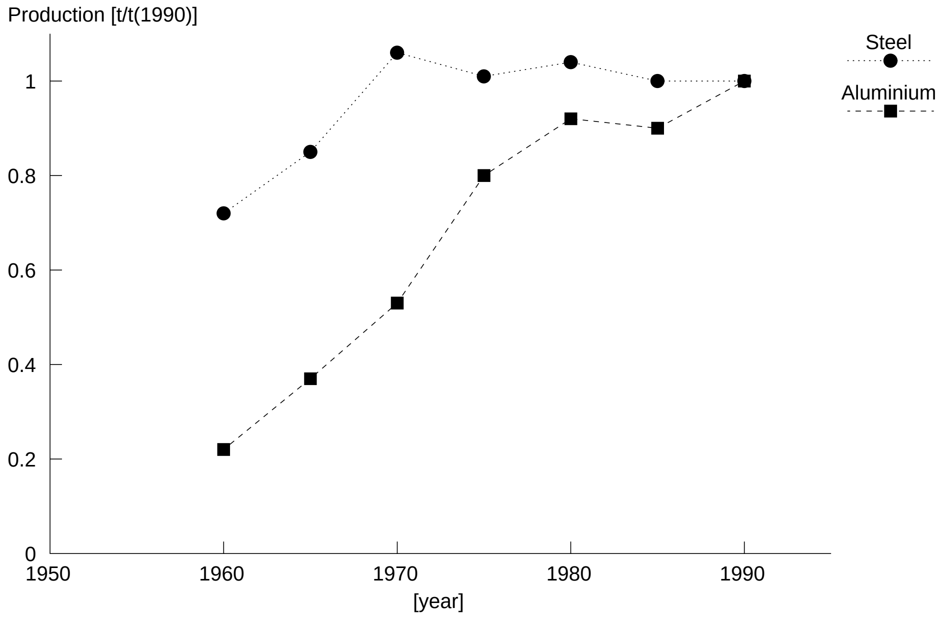

Figure 2.4 *EU+EFTA production of metals, 1960-1990 (1990=1) [9,18]*

Aluminium

Aluminium consumption is still rapidly increasing in Europe and is still in the expansion stage. This is however not the case for the primary aluminium industry. The Western-European primary aluminium industry, the key element for energy consumption forecasting, passed already through two main stages, the introduction-, the expansion stage and has largely reached the maturity stage.

The introduction stage of the West-European aluminium industry started after the Second World War and continued until the end of the fifties.
The expansion stage, from 1960 to the end of the ’80 s, started with significant increase of demand. The demand for aluminium for transportation equipment, construction and consumer electronics increased significantly as aluminium processing technologies improved. These plants were built close to the markets.

The maturity stage began at the end of the ’80s. Increasing competition and the reduced aluminium demand in Eastern Europe and the CIS countries resulted in significant aluminium exports from CIS countries to Western Europe. Aluminium demand growth decreased, while more aluminium scrap entered the market. As a consequence of such developments, primary aluminium production in Western Europe decreased and was relocated to countries with low electricity costs (Norway and France). Slower growth, very high capital costs and increased quality demands from customers made firms aware of the need to shift from low unit costs, based on economies of scale, to product development and quality. This results currently in closure of some major units and old and small plants with insufficient market potential.

The Dutch primary aluminium industry stabilised in the last 25 years, the aluminium recycling industry is however still rapidly increasing. A decline stage which follows the maturity stage in the industry life cycle theory has not been observed yet for aluminium consumption. Concerning recycling and aluminium alloys, new products are constantly developed, some of which have the potential of large scale production. Significant potential still exists for increased industrial activity. It is only in primary aluminium production, not in the recycling industry, that a mature phase in the life cycle can be observed.

Two primary aluminum smelters, Aldel Delfzijl and Pechiney Vlissingen, are operated in the Netherlands. Their history will be discussed separately.

The Aldel operation started in 1966. The plant was commissioned by a combination of Billiton (with alumina plants in Surinam), Alusuisse (with experience in aluminium production) and Hoogovens (driven by a hedging strategy because of the aluminium/steel competition and the good prospects for aluminium). The operation started as a result of the natural gas exploitation that began a few years earlier. Based on these gas reserves, cheap energy was provided by the national government for industrialisation projects. The investment decision for the aluminium plant was to a large extent based on these low energy prices [19]: the energy prices remain the key issue in its prolongation after 30 years.

The Pechiney operation started in 1972. The opening of the plant was closely connected to the delivery of cheap electricity from the nearby nuclear power plant in Borssele. The current plant is still operational for the next 15 years, there are no plans for early shutdown. The current plant consists of the older type of side-fed smelting cells. There are however no plans to upgrade the current plant. The future of the site beyond 2010 is still unclear. Coupled to the closure of the nuclear plant in 2007, which might endanger the delivery of cheap electricity, its long term future is uncertain.

Pechiney produces 120 different products, divided by size and alloy type. Three quarters of the production are extrusion poles, the remainder are slabs for rolling.

Steel

The Western-European steel industry passed through three main stages, the introduction-, the expansion- and the maturity stage, and is currently in the declining stage with a decreasing production trend.

The introduction stage of the West-European steel industry started at the end of the last century and continued until the '30 s. This was followed by the expansion stage to the end of the '60 s. These steel plants were initially built close to the iron ore and coal reserves. Later expansions took largely place in the same regions because of existing infrastructure and labour force. A trend existed however away from the resource sites towards site with good accessability to international trade routes. This trend was mainly initiated by the important reduction in transportation costs due to increased economies of scale, which allowed cheaper imports of resources from other continents.

The maturity stage began at the beginning of the '70 s. Increasing competition from other materials like aluminium and plastics reduced the steel demand. Exports were hampered by competitive production abroad. As a consequence of such developments, primary steel production in Western Europe decreased. Slower growth, very high capital costs and increased quality demands from customers made firms aware of the need to shift from low unit costs, based on economies of scale, to product development and quality. The level of concentration in the European steel market is modest and the market is best characterised as a wide oligopoly in mainly homogeneous products [20].

The Koninklijke Hoogovens en Staalfabrieken started its operation in 1918. In earlier years, the lack of local coking coal and iron ore were considered formidable obstacles. The rapid growth of the coal production in Limburg provided however an opportunity for steel production, based on national resources. The lack of cheap steel imports during WW I was also a main drive to start a Dutch steel producing industry for self-supply. The location IJmuiden was favoured because of its strategic location at sea, with good connections to suppliers and consumers. Strategic considerations played also a role (location in Limburg was considered to be more vulnerable to foreign invasions, the region was already heavily industrialized by the mining industry). The location in Rotterdam was long considered preferential because of lower transportation costs. IJmuiden was ultimately preferred above Rotterdam because of the significantly better underground stability, which reduced investment costs. The original company funding was generated by a large number of industries and the Dutch government. Already in the early years, Hoogovens was an internationally oriented industry. The whole site design was based on American plans. Only 12 years after the foundation, the company was already the largest exporter of crude iron in the world. The sale of by-products (blast furnace gas, blast furnace cement) proved in the early period already crucial to generate a profitable operation. Initially the production was limited to iron because of lacking investment funds. The steel production started in the 30's.

Production grew rapidly after WW II. After 1970-1975, production stabilised due to stabilising steel consumption in Western industrialized countries and rapid growth of steel production in developing countries (where the growth of global steel consumption is concentrated). Production at Hoogovens shows still a slight upward trend due to de-bottlenecking of the existing site.

The other steel producing industry in the Netherlands, Nedstaal, started its operation in 1938. The plant is located in Alblasserdam, 20 km south of Rotterdam. Since 1975, Nedstaal is for 100% owned by the German Thyssen Stahl AG. After a number of bad years, current plans are to halve steel production because Nedstaal cannot compete with bulk steel producers because of lacking investments in new technology [21]. The company operates therefore in market niches with high quality requirements. It produces predominantly wire products for the transport industry like springs, ball barings and fastenings. The lacking competitiveness of the Dutch EAF production is remarkable and different from the developments in most other industrialised countries: the Dutch steel industry diverges from the international trend as production is even more shifting towards blast furnace steel production.

2.4 Importance of location and infrastructure

Locational choices in the steel and aluminium industry are influenced by several factors. Important factors are the proximity to cheap natural resources, a position close to consumer markets, the availability of cheap labour resources.

Within Western Europe, a division can be made into three categories of steel complexes. The first type are coastal complexes with low transportation costs. The second type are older established inland complexes on the locations where iron ore or coal were formerly available. The third type are growth pole complexes that have been stimulated by public authorities according to their regional policy.

There is a trend in the steel industry towards more international trade with plants at strategic locations with easy access to cheap global resources (i.c. coastal complexes with harbour facilities for large seagoing vessels). Such plants can also easily serve the major consumer markets. This trend is clearly in favour of the Hoogovens plant in IJmuiden.

In the aluminium industry, low electricity prices are a key factor in the location of new plants. As electricity prices used to be determined by national policies, the location choice for aluminium plants was largely a choice for a certain country. This may change in future years, if the European electricity market is liberalised. Transportation costs and the availability of other national resources are to a lesser extent important for primary aluminium smelters, but again more important for secondary production sites (with sufficient regional availability of cheap aluminium scrap as key issue).

In general, industries which are linked in a product chain tend to locate in another’s vicinity. Such joint locations of linked industries form complexes.

To locate in or near a complex can be attractive for the producer since he will find already a high developed infrastructure, a labour market where certain skills are present, and various auxiliary services.

2.5 Energy use and energy efficiency

Energy balance summary

Table 2.7 shows the energy balance for different processes in the basic metal industry. Minor processes like cold rolling and wire drawing, aluminium rolling are not listed separately. Anode production and coke production are important, closely related processes that are not included in SBI 27.

Table 2.7 *Primary energy use for processes in the basic metal industry, 1993 (SBI 27)*

Process	Output [kt pa]	Primary energy[1] [PJ pa]
Aluminium from alumina	232	29.0
Aluminium from scrap	139	0.6
Pig iron from ore (BF+sinter+pellets)	5404	80.0
Cast steel from pig iron (BOF route)	5812	5.5
Cast steel from scrap (EAF route)	189	1.0
Hot rolled steel from cast slabs	6000	16.7
Zinc production	210	2.2
Other		17.0
Total SBI 27		158.0
Anode production	400	15.0
Coke production	2330	15.3

[1] Assuming 40% efficiency in electricity production.

The primary steel and primary aluminium production activities at Pechiney, Aldel and Hoogovens represent the major part of the total energy consumption in the process chain of these metals. Note also the significant energy consumption for anode production, which is for the major part accounted for by the Aluchemie production plant in Rotterdam.

Aluminium

For the period 1989-1995, the non-ferrous metals industry, including all major primary and secondary producers, had a voluntary agreement with the Ministry of Economic Affairs on energy efficiency. The improvement to be achieved in 1995 was 8% compared to the 1989 level. Most of the energy use for the primary aluminium production was however not included in these figures. The agreement excluded the non-energy use of 14.3 PJ in 1994 (see also Table 2.3). Measures included:

1. improved process efficiency
   - reduced materials losses (2%)
   - CHP, biogas, new heating systems (1.5%)
   - new equipment like extruders, ovens (2%)
2. improved energy management
3. improvements in non-energy use.

The energy efficiency increased between 1989 and 1995 by 8%. This improvement was measured on a process level and consisted of one third good housekeeping, one third energy savings and one third new equipment; on a sector level it was balanced by decreases in energy efficiency due to additional measures for the environment of almost the same magnitude. The efficiency of non-energy use increased between 1989 and 1993 by 1% (this is not included in the voluntary agreement).

Steel

For the period 1989-2000, the ferrous metals industry (Hoogovens and Nedstaal) has a voluntary agreement with the Ministry of Economic Affairs on energy efficiency. The improvement to be achieved in 1995 is 10% compared to the 1989 level, and 20% in 2000 compared to the 1989 level. The agreement excludes the non-energy use at Hoogovens of approximately 70 PJ (i.e. the heating value of the blast furnace energy inputs minus the heating value of the energy outputs) [22]. Measures include [23]:

1. Good housekeeping (pinch technology, reuse of waste steam, adjustable electric drives), representing 10% of the efficiency improvement.
2. Energy savings (CHP, reuse of flare gases, gas expansion), representing 50% of the efficiency improvement.
3. Process adjustments (increased coal injection, increased scrap use), representing 40% of the efficiency improvement.

Hoogovens' improvement in 1994 was 11%, compared to the energy efficiency in 1989. A significant correction has been applied regarding additional energy use for environmental pollution abatement technologies (correction 0.9 PJ in 1994). Concerning Hoogovens, good housekeeping proves to be more relevant than expected with 28% of the total efficiency improvement. Separate data for Nedstaal are confidential.

3. PRODUCT DEMAND

3.1 Aluminium

Looking at the aluminium chain, the following imports and exports are relevant:

1. bauxite
2. alumina
3. aluminium
4. aluminium alloys
5. aluminium products
6. aluminium scrap.

Data concerning transboundary flows are shown in Table 3.1.

Table 3.1 *Transboundary flows in the aluminium chain, 1993 [24]*

	SITC Code	Export [kt/year]	Import [kt/year]	Net export [kt/year]
Bauxite	260600000	11	151	-140
Alumina	281820000	93	471	-378
Aluminium	760110000	135	265	-130
Aluminium alloys	760120100-760120900	263	102	161
Aluminium prod.	760200110-761690990	211	210	1
Aluminium scrap	760200110-760200900	140	125	15

Table 3.1 shows that the Netherlands is a net importer of bauxite, alumina and aluminium, while the trade balance is positive for aluminium alloys and aluminium scrap. The trade for aluminium products is balanced. One should add that aluminium in complex products (cars, consumer electronics etc.) is not included in the group of aluminium products. For aluminium scrap, a small net export exists.

Alumina is for 90% imported from Jamaica and Surinam. The aluminium trade consists mainly of imports from low cost producing countries (Russia, Norway, France) and exports to surrounding European countries. Trade of aluminium alloys is for 90% concentrated within the European Union. For scrap, imports come from surrounding European countries, exports go to surrounding countries and a significant fraction (25%) to Asian countries.

The alumina market is thus dominated by countries with bauxite reserves, the aluminium market is dominated by countries with cheap electricity. Location close to aluminium markets is however still beneficial, shown by the significant intra-European trade. The alloy market is dominated by producers with close links to the product markets: a typically intra-European business.

The global aluminium markets are analysed in Figure 3.1. Western Europe is an important net importer, just like Asia. The surplus production capacity is concentrated in North America, Latin America and Oceania.

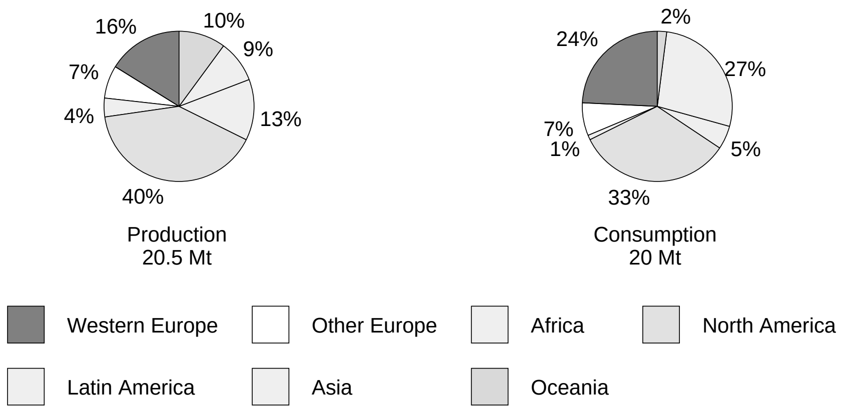

Figure 3.1 *Global aluminium production and consumption, 1992 [25]*

The European aluminium market trends are shown in Figure 3.2. It shows that production grew very rapidly since the '60s, but is stabilising in the last decade. Consumption is growing more rapidly than production; aluminium imports make up the difference.

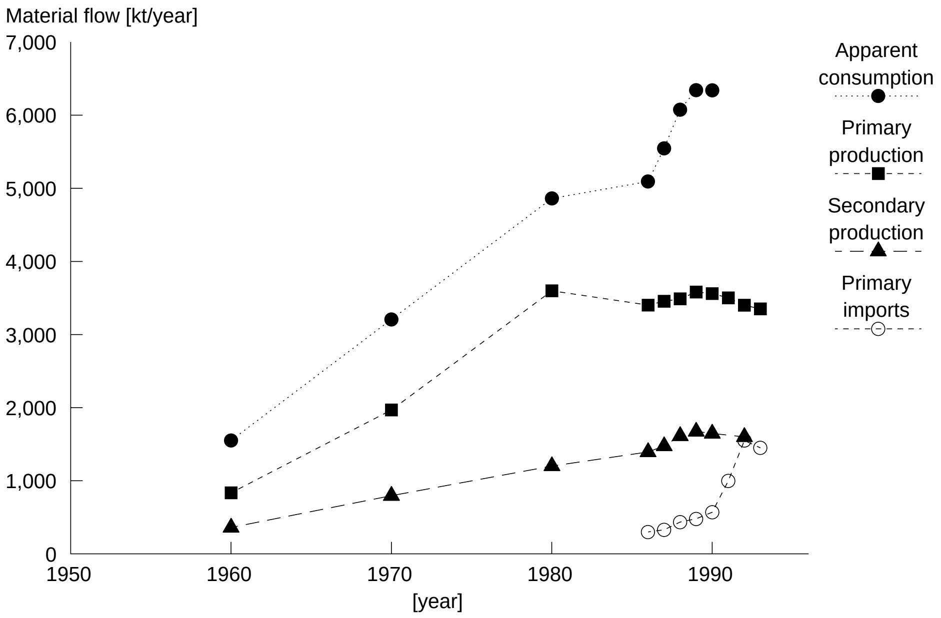

Figure 3.2 *European aluminium production and imports (EU+EFTA)*

Especially in the last 5 years, the imports from the former Eastern European countries (especially Russia) grew very rapidly, because the aluminium demand in Eastern Europe declined significantly and the surplus production was sold on Western markets. As a consequence, the primary aluminium production in Western Europe did not grow in this period and was even reduced. It remains to be seen whether the Russian exports will be reduced when the Eastern European market recuperates.

The Western European aluminium market for aluminium applications is analysed in Table 3.2.

Table 3.2 *Western European aluminium end use [26]*

End Use	[%]
Transport	29
Construction	23
Packaging	12
Others	36
Total	100

Table 3.2 shows that the transportation sector is the largest single category of applications (vehicle engines and drives). This is followed by the construction sector (window frames, cladding) and the packaging sector (beverage cans, foils, laminates). The category others includes the machinery industry and consumer electronics, both important sectors for aluminium. Per capita aluminium consumption is relatively low, compared to the United States and Japan (see Table 3.3).

Table 3.3 *Per capita aluminium consumption [27]*

Area	1975 [kg/capita]	1980 [kg/capita]	1991 [kg/capita]
OECD-Europe	9.9	13.9	18.0
USA	20.4	25.8	26.7
Japan	12.2	20.7	31.6

Table 3.3 indicates that aluminium consumption in OECD-Europe still lags behind aluminium consumption in the USA and in Japan. The difference in aluminium consumption between Europe and the USA is mainly accounted for by the American aluminium drinking can (predominantly steel cans and glass/plastic packaging in Europe) and the more extensive aluminium use for cars (because of higher car ownership rates and because American cars are on average 40% heavier than European cars). The Japanese situation is different because of the significant exports of cars and electronics (important aluminium applications) to other countries.

In order to forecast Western European aluminium demand, historical trends are analysed and extrapolated. The basic assumption behind this extrapolation is the often observed ‘S-curve’ for materials consumption (see also Figure 2.4) [28,29]. No decrease in demand is assumed in the period that is studied. Figures 3.3 shows the historical demand and extrapolations for aluminium, relative to the demand in 1992. This aggregated approach can be illustrated by important developments on a more detailed level. In the transportation sector, the body-in-white of passenger cars will increasingly be built from aluminium (see Paragraph 3.3). This single product represents a potential aluminium market of 2-3 Mt per year. In building applications, growth of the renovation market and increased use of aluminium window frames due to substitution of tropical hardwood and PVC window frames represents an additional market of 0.5 Mt aluminium per year. Developments in other sectors will to a large extent depend on the future growth of capital investments and consumer expenditures in Europe, but will also show a significant growth. Steel will to some extent be substituted by aluminium in many applications, while competitors like plastic and magnesium may substitute some aluminium.

The fraction primary production will decrease as more secondary aluminium becomes available. Because of the still rapidly increasing aluminium consumption and because of the aluminium storage in long life products (especially construction and capital equipment), recycling cannot substitute primary production. The estimate for recycling in Figure 3.3 should be considered an optimistic estimate. Consequently, the estimate for consumption of primary aluminium is a low estimate. A key question in Chapter 13 is where this primary and secondary aluminium will be produced.

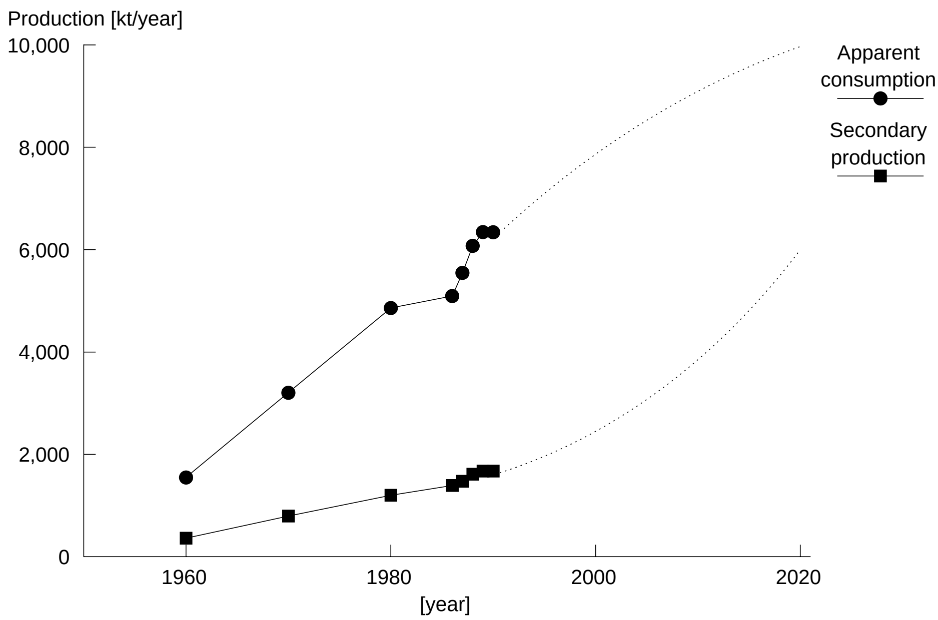

Figure 3.3 *Historical demand and extrapolation for aluminium in Western Europe (EU+EFTA)*

3.2 Steel

Looking at the steel chain, the following imports and exports are relevant:
1. iron ore
2. coking coal
3. coke
4. steel semi-finished products
5. steel products
6. steel scrap.

Data concerning transboundary flows are shown in Table 3.4.

Table 3.4 *Transboundary flows in the steel chain, 1993 [24,30]*

Intermediates	SITC Code	Export [kt/year]	Import [kt/year]	Net export [kt/year]
Iron ore	260111000	1024	8553	-7529
Coking coal	270112100	2	4944	-4942
Coke	270400190	877	264	613
Semi-finished and finished steel		5727	4339	1388
Steel products		na	na	na
Steel scrap		5581	3522	2059

Table 3.3 shows that the Netherlands is a net importer of natural resources (iron ore and coking coal) but a net exporter of steel, steel products and steel scrap. The steel industry contributes significantly to the export oriented, energy intensive character of the Dutch economy.

Because the Dutch steel industry is export oriented, a market analysis must focus on larger regions.

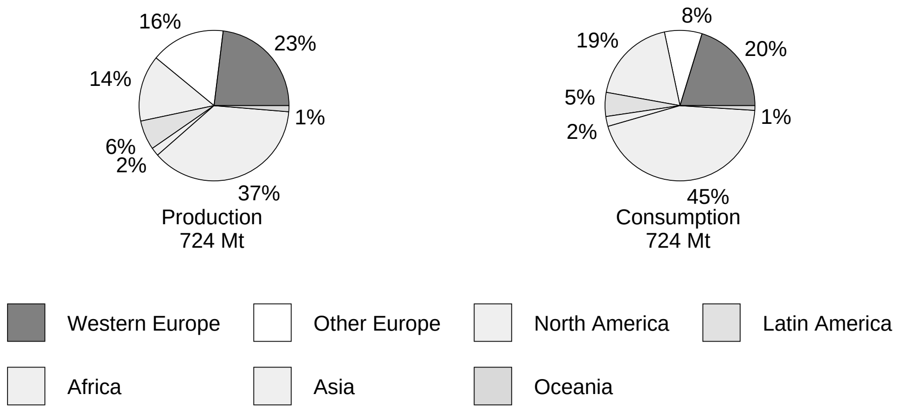

Figure 3.4 *Global steel production and consumption, 1994 [31]*

Figure 3.4 shows the global steel production and consumption percentages of the different continents. The extremely low figures for Africa are remarkable. The situation in North America, Europe and Asia is more balanced. Most countries in these areas possess their own production industries because steel production was considered a key industry in the industrialisation process.

The only area where a structural overcapacity exists is Western Europe. The capacity creep in Western Europe is around 1.5% per year. Europe’s traditional trade surplus in steel is however set to decline. Current capacity utilisation at the height of the upturn is 94%; in the trough of recession (expected for the year 2000) it will only be 78%. The combination of creep and demand fluctuations results in rising production in periods with high prices, followed by periods with low prices and plant closures. The biggest hope for coming years is the South East Asian market. However, steel producers in the United States and in Russia will add considerably to the existing steel capacity. Additional Eastern European production capacity poses in coming years a serious threat to Western European steel production [32].

Per capita steel consumption in Western Europe is relatively low, compared to the United States and Japan (see Table 3.5). This difference is mainly related to differences in GDP, differences in production structure (higher per capita car production in Japan), differences in product characteristics (heavier cars in the USA) and differences concerning materials applications (more steel use for construction in the USA and in Japan).

Table 3.5 *Per capita apparent crude steel consumption [30]*

Area	1970 [kg/capita]	1985 [kg/capita]	1993 [kg/capita]
OECD-Europe	500	291	282
USA	680	434	400
Japan	650	607	647

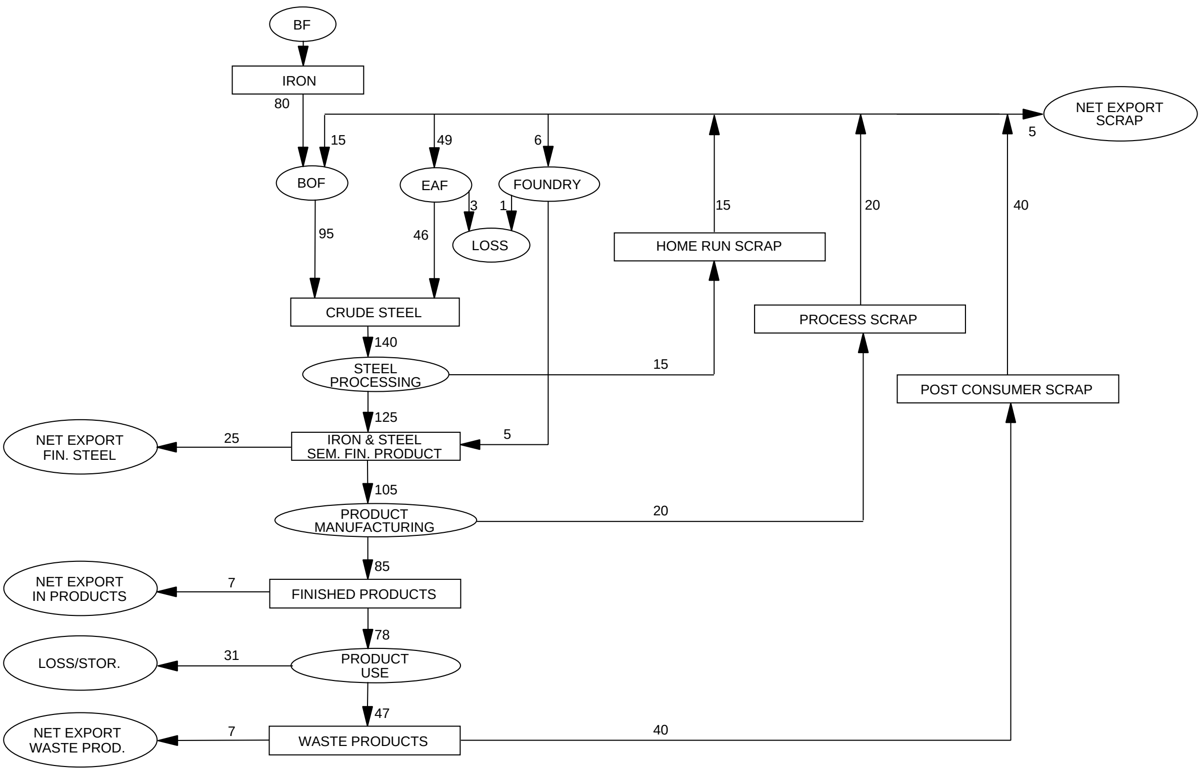

Figure 3.5 *EU+EFTA steel balance, 1992 [Mt pa]*

Figure 3.5 shows why steel recycling figures are not suited for assessment of the remaining recycling potential. The net export of finished steel, steel products, waste products (used cars, used appliances) and steel scrap accounts for 44 Mt of steel, i.e. 31% of the total crude steel production. Losses and storage account for another 31 Mt or 22%. A significant part of this amount is storage. The storage is predominantly caused by the still significantly increasing building stock, infrastructure stock and stock of production equipment. The steel balance will be more balanced if the total steel stock in products stabilises (input = output), but this may take decades. The figure shows clearly why primary steel production will remain the dominant production technology in Western Europe in coming decades, despite the small losses in the steel system, unless significant amounts of steel or steel scrap are imported.

In Table 3.6, the steel consumption is divided into semi-finished product types.

Table 3.6 *Apparent consumption of semi-finished steel products, EU+EFTA, 1992*

Type	Amount [Mt pa]
Sheet	40
Bars	18
Wire rod	15
Tubes	14
Sections	8
Tinmill products	5
Other	5
Total	105

Sheet is the largest subgroup, followed by bars and wire rod. Sheet is applied in cars, consumer electronics and cladding. Bars are used for construction and production equipment. Wire rod is predominantly used for concrete reinforcements.

Apart from a subdivision into semi-finished products, it is also possible to make a subdivision into product groups where steel is applied. This is shown in Table 3.7.

Table 3.7 *Steel consumption in products, EU+EFTA, 1992*

Product group	Amount [Mt pa]
Machines & installations	25
Construction	23
Transportation	13
Packaging	4
Consumer electronics	4
Furniture	4
Others	4
Total	78

The product group machines and installations is the largest subgroup. It contains products like machines, power lines, pipelines. Construction is the second largest group. It includes reinforcement steel, structural steel and steel cladding. These two large groups are followed by the less important groups (at least in weight units) of transportation, packaging, consumer electronics and furniture. The distribution among product groups will probably not significantly change in the next decades. The analysis of the steel applications indicates that the bulk of steel is applied in investments goods. As a consequence, higher investments imply a higher steel consumption.

In order to forecast Western European steel demand, historical trends are analysed and extrapolated. The basic assumption behind this extrapolation is the often observed 'S-curve' for materials consumption [28,29]. No decrease in demand is assumed in the period that is studied. Figure 3.6 shows the historical demand and extrapolations for steel, relative to the demand in 1992.

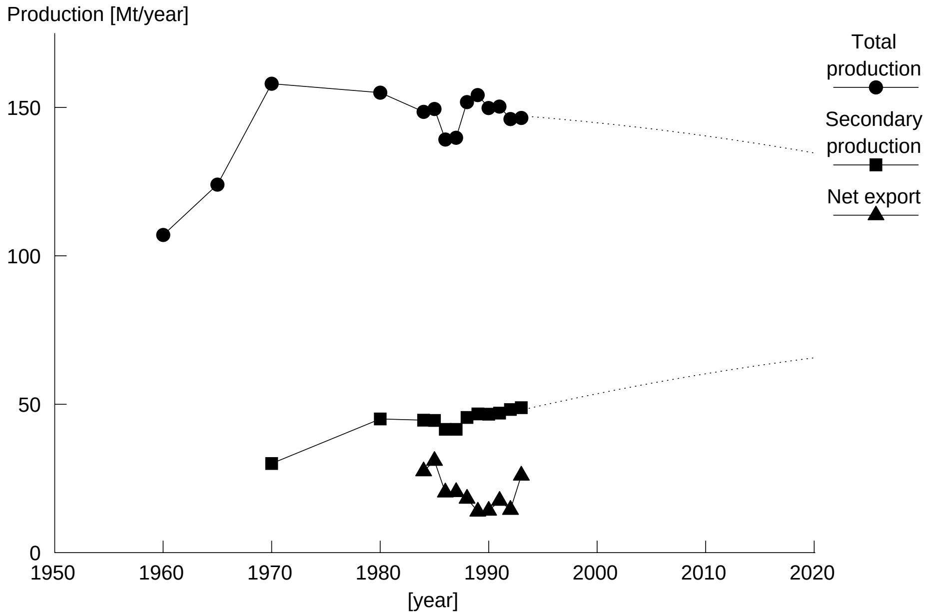

Figure 3.6 *Historical demand and extrapolation for steel in Western Europe [30,33]*

3.3 Steel and aluminium competition

Materials are used in products. The required amount of materials depends on design standards or on rules of thumb. Design standards are generally based on physical material properties:
- the average material characteristics
- the variation in material characteristics.

The relevant material characteristics can be grouped in categories constructive properties; chemical resistance; and processing properties.

Most sheets are used for vessels, body works, cladding for which in the normal situation strength characteristics are not fully exploited. Thickness is largely determined by random incidents of stress and strain during use. Standards are for such situations largely based on rules of thumb concerning impulse stress and displacement perpendicular to the sheet surface. General thickness ranges are denoted in Table 3.8.

Table 3.8 *Normal thickness ranges for sheet applications*

Application	Steel [mm]	Aluminium [mm]	Ratio [-]
Offshore/rail/main constructions	5-30	-	-
Industrial installations (piping, vessels, equipment)	2-10	3-10	1.5
Cladding/automotive	0.5-1.2	0.7-1.5	1.7
Light indoor applications, packaging	0-0.7	0-1.0	1.7

Rigidity of sheet metal for random incidence is determined by the thickness to the power of 3 and bending strength to the power of one. Therefore, doubling of strength will save only a limited share of material inputs in sheet applications, whereas in purely constructive applications this relation is more approaching linearity. High strength steel still has other limitations for application in constructive elements. E.g. welding can be impossible without losing most of the increase in strength.

Chemical resistance, especially corrosion resistance in outdoor applications results in major advantages for aluminium. A protective oxide layer arises which protects the material from further damage. Steel normally needs protection for outdoor or moist environments. Therefore it is mostly coated with zinc, tin or laquers. In situations where coatings can be damaged in subsequent production, fixing or use, aluminium has a major advantage. Coating technologies for steel are very advanced and mature, reflecting the advanced stage of steel in its economic life cycle. Stainless steels is another option to overcome the corrosion problems of steel, but the much higher price (5 times as expensive as conventional steel) prevents large scale substitution.

Aspects of production technology and design are among the major determinants for material consumption. For steel, rolling is the foremost shaping technology. Apart from sheet, which is characterised by its thickness, hot rolled products are standardised in shape to a large extent because of the large capital investments needed for rolling equipment. Large quantities of one profile shape are necessary to operate hot rolling in a profitable way. Subsequent to hot rolling, cold forming techniques deliver the large diversity of products well known. Sheet is the major input for all cold forming techniques, and therefore constant material thickness is a dominant property of steel products. It poses a challenge to designers to choose thickness and shapes in such a way to minimise material inputs. Advanced possibilities exist in mass products, especially car bodies and beverage cans, where pressing technology in three dimensions is cost-effective and delivers sufficient rigidness with very thin sheet. However, most steel is applied in investment goods like buildings, installations and heavy equipment. Optimising in this field is not cost-effective because of small repetition and high complexity. Here advanced design techniques (CAD/CAM) may be directed to material economy, using standard elements. However, in steel construction design, a trend towards higher material inputs through standardisation and rationalisation has taken place in the last decades. This reflects the increasing ratio of labour costs over material costs. For example, wide span composite lattice girders have been almost completely replaced by solid beams in industrial buildings.

For aluminium, extrusion is the dominant technology in manufacturing most products. Unlike hot rolling of steel, investments for extrusion dies are small, and the diversity of shapes is enormous. Extrusions require minimum flange thickness of 1 to 1.5 mm, depending on the design. But apart from that there is an almost unlimited freedom to optimise the material input for specific profiles. Comparing window frames of steel and aluminium reveals the design possibilities, with aluminium incorporating all kinds of flanges, cavities and ribs, whereas a steel frame component basically remains a tube.

Similar advantages of shapes and design for aluminium exist for casting applications. Injection moulding here is a prominent technology, only applied for aluminium. To conclude, design opportunities to reduce material, as well as general possibilities in form and design are significantly better for aluminium.

Due to normal variations in material properties, standards for safe or failure free production and use are set higher than a perfect homogeneous product would require. In building materials, standards for wood or bricks allow only 10-20% of the average maximum stress on these materials. Due to its higher homogeneity, steel standards allow design stresses of 40-60%. This does however still allow for improvement if steel production technology improves accordingly. It has to be mentioned in this respect that these safety margins account for excessive stress situations and other eventualities. Standards for constructive use are not likely to be reduced substantially in the future.

Properties of some characteristic aluminium alloys and steel types are listed in Appendix A.

The competition between steel and aluminium will now be analysed on more detail for the following cases:
1. passenger cars
2. outside cladding of buildings
3. beverage cans.

1. Passenger cars

Aluminium has in the last decades gained a firm place in the automotive market. This implied substitution of other materials, primarily substitution of cast iron and steel. The current aluminium content is approximately 7-8%. The advantages of aluminium compared to steel are its light weight and design flexibility. Current aluminium applications in automobiles include radiators, heat exchangers, wheels, cast engine blocks, body panels and space frames. While aluminium's cost when compared to steel is a disadvantage, the technology being developed, combined with the life-cycle economies aluminium offers, can offset this factor [34].

Key technological advances required for additional aluminium use are:
- cheaper aluminium sheet manufacturing technologies
- improved forming processes for extrusions to reduce the number of parts in an assembly
- improved fastening technologies to substitute the current spot welding
- surface pretreatment methods for the improved adhesion of coatings.

In the case of a body-in-white (the frame and structural panels), aluminum is for high production volumes (>>25,000 units per year) more expensive than steel (difference 1000 NLG) because the raw material costs are higher (4/5 of the cost difference) and because the product assembly costs are higher due to the higher welding costs (1/5 of the cost difference). Manufacturing costs for product parts are almost the same for steel and aluminium. One should add that the additional costs are zero or there is even a cost gain for aluminium in case of low production volumes (<25,000 units per year).

The specific weight of aluminium substitutes for steel depends on the steel quality and the aluminum quality and the product specifications. Even within cars, substitution coefficients differ to a large extent (Table 3.9). Only the aggregated body-in-white will be discussed in more detail.

Table 3.9 *Substitution characteristics for different products [35]*

Car part	Engineering constraint	Al/Fe [t/t]
Boot lid	tensile strength	0.42
Drive shaft	torsion rigidity	0.80
Fender		0.55

The weight of an aluminium car body is significantly lower than the weight of a reference steel body (140 kg vs. 280 kg) [36]. One should add that improved steel qualities and design of the steel body-in-white can reduce the relative saving of the substitution by aluminium. New steel types show a yield strength in the range of 300-400 MPa compared to 200 MPa for conventional steel, the weight saving by aluminium substitution is reduced to 45% instead of 55%. Steel types with even higher design strengths are currently under development [37]. Design by systems engineering is another significant option to achieve weight reduction. The steel industry states that a total weight reduction in the range of 35% (i.c. 180 kg vs. 280 kg) is possible [38]. In such a case, the weight reduction by substitution of aluminium for steel in the body-in-white is only 22% (40 kg).

A life cycle cost comparison is shown in Table 3.10. These data refer to macro-economic benefits (excluding fuel taxes), including severe reduction of NO_x emissions (80%). The weight saving is in this case assumed to be 150 kg. This includes all substitution options (body-in-white, hood/bonnet, deck lid, doors, fenders). The data are based on an average annual distance of 13,000 km and a service-in-life of 10 years. A major uncertainty represent repair costs. According to the steel industry, these costs are substantially higher. The aluminium industry is however developing systems to reduce these costs. In this case, additional repair costs of 1000 guilders per car are assumed over the lifecycle of the car.

Table 3.10 *Life cycle cost savings due to increased aluminium use for conventional gasoline fuelled cars [39]*

	[NLG/car]
Fuel savings	1300
Smaller engine	300
Additional car wreck value	600
NO_x reduction	300
Average repair costs	-1000
Total	1500

On the longer term, the competition is not limited to steel and aluminium. Aluminium is in most applications challenged by fiber reinforced plastics and on the longer term possibly by magnesium. Aluminium, steel and plastics are currently fiercely competing. The ‘best’ solution is unclear. For example, Audi opts for aluminium while Mercedes opts for carbon fiber reinforced plastics. The recent improvements in steel may however counteract such substitution.

The substitution coefficient [t/t] of steel by aluminium is determined by the engineering characteristics of the product parts. Table 3.11 lists some comparisons, based on different characteristics. These figures indicate that the substitution coefficient can significantly differ for different product parts. As a consequence, design optimisation requires detailed analysis.

Table 3.11 *Comparison of steel and aluminium [40]*

		Steel	Aluminium
Density	[kg/m^3]	7800	2700
E-modulus	[MPa]	200	71
Component weight			
Stiffness constrained	[kg/kg steel]	1	0.45
Volume constrained	[kg/kg steel]	1	0.35
Constant denting energy	[kg/kg steel]	1[1]	0.52[1]

[1] Steel quality bake-hardening no. 400 vs. aluminium no. 2036-T4.

In conclusion, aluminium can still substitute considerable amounts of steel in passenger cars. There is probably a certain weight reduction compared to steel, the extent of this reduction is however unclear and depends to a large extent on the ongoing improvements in the steel car design. The aluminium car is probably more expensive than the advanced steel car. The additional costs will to a large extent be determined by the additional maintenance and repair costs. The most probable development is an increased use of aluminium in the low-volume car market, while the high volume market will probably be served by the steel industry.

2. Outside cladding of buildings

Outside cladding materials for walls of industrial buildings and office buildings are often made from steel or aluminium. Metals face in this market competition from other materials like fibre cement, concrete based products and plastics. Both steel and aluminium profiled sheet are used either single, double with a cavity or as a sandwich panel with polystyrene, polyurethane or honeycomb paper cores for insulation. The outside is often covered with several layers of coatings. Important product criteria are load capacity, weathertightness and coating performance [41]. The materials thickness, profile and weight is determined by impact resistance and tensile strength. Typical steel skin thickness is 0.7 mm but can be as thin as 0.4 mm for composite sandwich panels [42,43]. Aluminium sheets are far softer and if the sheeting can be subjected to accidental loads, damage can occur. Such damage can to some extent be counteracted by the use of thicker sheet. Typical outer skin thickness of aluminium is a factor 1.25 (0.2 mm more) than the thickness of the steel skin. The cladding profiles are either sinusoidal or trapezoidal with indented webs or flanges for greater stability.

Data concerning the use of aluminium and steel cladding are lacking. From a survey of Dutch cladding contractors, steel is estimated cover 80% of the metal facade market, aluminium covers the remaining 20%. For profiled roofing, steel is even more dominant, because most roofs are covered with insulation and felts, taking care of weathertightness. Aluminium is only applied in relative niches, e.g. in special corrosive environments; in large light shedlike roofing without additional covering or insulation; or where uncoated ‘natural’ material is favoured by architects.

A profiled sheet steel cladding on framing with insulation and inner lining of plasterboard costs approximately 75 NLG per m^2, while the same system in aluminium costs approximately 90 NLG per m^2 [44]. Prices for profiled and coated metal sheets range from 10 to 30 NLG per m^2 for steel and from 20 to 40 NLG per m^2 for aluminium.

An estimate of the European market can be made, based in construction statistics. Total non-residential building construction in the EU+ EFTA area is approximately 210 million m^2 per year [45]. It is estimated that one quarter of these buildings has metal cladding. Assuming an average ratio of 0.5 m^2 outside cladding per m^2 floor space, the required amount of material is 10.9 kg steel per m^2 cladding and 4.9 kg aluminium per m^2 cladding. The total materials demand is thus at most 1.1 Mt steel or 0.5 Mt aluminum per year. Figures for metal roof cladding are estimated to represent twice these amounts.

To conclude, steel in standard facade cladding has a dominant position, due to its price advantage and adequate coating technology. Possibilities for aluminium remain limited to special applications.

3. Beverage cans

Beverage cans have been developed in the USA before WW II. The first cans consisted of three parts: a bottom, top and body part and were made from steel. Because this was an expensive production process, a new can type was developed in 1958. This can consisted only of two parts: one part that consisted of the bottom and the side walls and a separate top. This new can type was made from aluminium. The early technique was slow and required too much aluminum to be competitive. The process was in 1963 improved by Kaiser to the current aluminium can production process.

As a consequence, aluminium cans became popular. The steel industry counteracted by development of a two-piece steel can. This can was a success in Europe, where the aluminium can was later introduced than in the United States. In the USA however, aluminium cans had gained a decisive competitive advantage, and serve nowadays more than 95% of the beverage can market [46].

Modern beverage cans are an assembly of two parts and are available in three types [47]:
- a steel body with a steel top
- an aluminium body with an aluminium top
- a steel body with an aluminium top.

The first type has been developed by Hoogovens because of its superior recycling potential, but faces opposition from the traditional beverage industries who still prefer the steel body/aluminium top type. The current content of these cans is 0.33 l with a diameter of 65 mm and a height of 116 mm. The weight of the three types is shown in Table 3.12. Significant weight savings are still possible, eg for steel a weight of 20 grammes per can is aimed for in the year 2000. Similar trends can however also be found for aluminium (see Figure 3.7).

Coupled to the light weight of the aluminium can (see Figure 3.7) aluminium became a cost-effective substitute. The weight of the steel beverage can is currently approaching the weight of the aluminium beverage can. Aluminium beverage can makers traditionally strived for weight reduction because of the high fraction of materials costs in their total production costs, the potential for further savings through weight reduction seems limited.

Table 3.12 *Weight of state-of-the-art beverage cans [48]*

	[gr/can]
Steel/steel	23
Aluminium/aluminium	15
Steel/aluminium (est.)	20

The energy use for can production is small (<5%) compared to the production energy for the required amount of steel sheet and aluminium sheet. As a consequence, the energy content of both can types depends on the recycling rate. Recycling rates for steel cans are higher because they can be separated from other waste fractions by magnets. For aluminium beverage cans, new separation technologies are being developed (see Section 10.1).

Table 3.13 *Fraction aluminium cans in the total beverage can market (1989 situation) [49]*

Country	[% Al cans]
Austria	100
Greece	100
Sweden	100
USA	100
Italy	70
UK	50
Netherlands	17
Germany	12

European cans are currently still primarily of the steel type, while the aluminium can dominates in the United States (see Table 3.13). There exists however significant variation in the fraction aluminium cans in different European countries.

The aluminium beverage can is made from two alloys. The bottom is made from Al3004 alloy (1.2% Mn, 1% Mg), while the top end is made from Al5182 alloy (0.4% Mn, 4.5% Mg). This has consequences for closed loop recycling: separation of both alloys is required. Downcycling onto cast aluminium poses however no problem.

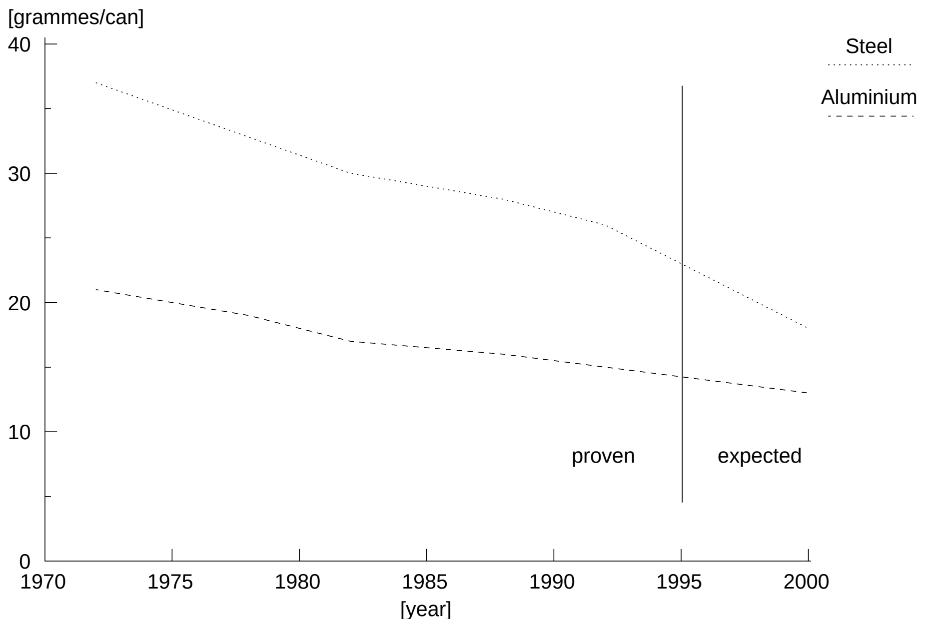

Figure 3.7 *The downward trend in steel and aluminium beverage can weight in the United States [50]*

Beverage can consumption in Western Europe was in 1993 20 billion per year, compared to 100 billion cans per year in the USA. This difference is caused by the significant fraction of glass and plastic beverage containers in Europe. The European beverage can market is forecast to double in 2000. The current division is 50% steel and 50% aluminium. This represents a steel consumption of 0.46 Mt steel and 0.3 Mt aluminium in the year 2000. Materials losses in can production due to cutting circles from sheets are approximately 12-14%, so the input into can production is 0.53 Mt steel and 0.34 Mt aluminium. These figures should be compared to the total Western European apparent steel consumption of 155 Mt and the total apparent aluminium consumption of 7 Mt pa. The beverage can market is however a high quality market with high added value so in monetary terms, it is much more significant. A second consideration is that the beverage can market it is a rapidly growing market, which will become more significant in coming years.

Concerning prices, the relative prices of both cans are compared in Table 3.14.

Table 3.14 *Average mid-1987 cost per container for material used in manufacture of 355 ml containers [51]*

	Aluminium [NLG cents]	Steel [NLG cents]
Raw material	9.34	6.46
Container manufacturing	6.48	7.73
Filling	na	na
Distribution	0.10	0.16
Process scrap credit	-0.83	-0.00
Total cost	15.09	14.35

Table 3.14 shows that the cost differences between both materials options are small. 1987 was a year with average aluminium and steel prices (see Chapter 5 and 7). One should add that the data represent the 1987 situation with an aluminium can of 17 grammes and a steel can of 38 grammes. The weight reduction of steel cans to 25 grammes improved its competitiveness significantly (a reduction of materials costs for steel cans by 35%). The weight reduction of aluminium cans to 14 grammes however balances the significance of this improvement (a reduction of materials costs for aluminium cans by 18%).

In conclusion, neither of both materials has a distinctive advantage in the European beverage can market. Especially the European steel producers like Hoogovens seek however aggressively for light weight solutions by increased materials quality and improved can production technology. Aluminium can production technology seems to have reached its technological limits, so steel may gain a competitive edge compared to aluminium. This may enhance the use of steel beverage cans in Europe and open markets abroad that are currently dominated by aluminium cans (like the US market).

Increased aluminium can recycling poses however still a significant improvement potential in the European aluminium can life cycle, where the collection rate is very low (contrary to the US market, where recycling rates of 65% are achieved). This option is further analysed in Section 10.1 [52].

The beverage can market is a good example where steel and aluminium are fiercely competing. The result is a materials technology and processing technology of a very high standard for both materials, which is still improving. The competition seems in this case beneficial for the environment. This conclusion does off course not address the issue if metal beverage cans are better than glass reusable systems or other forms of distribution.

The impact of downgauging trends on national materials and energy consumption

Comparison of developments for steel and aluminium in these three markets shows apparently more progress in the steel production technology than in the aluminium production technology. The main reason for this difference is that steel producers face tough competition from other materials, while aluminium producers see their production still rise without major materials research efforts. Another important aspect is off course that there is a much larger number of steel producers than aluminium producers, and the financial turnover in the steel industry is much higher than in the aluminium industry. As a consequence, much more R&D funds are generated for steel research than for aluminium research. This situation may change in the future if aluminium production matures.

The currently stabilising steel consumption can be related to the substitution by other materials and the shift towards improved materials quality and improved processing technology that results in reduced materials consumption. The example of the passenger car and the beverage can illustrate this development. These kinds of dematerialisation effects do significantly influence materials consumption and thus energy demand for materials production, but they are not included in the analysis of energy efficiency developments. On the contrary, higher quality results often in increased energy demand per tonne of material and is only rated as increased energy intensity per unit of production. Proper analysis of dematerialisation is necessary for relevant analysis of industrial energy savings.

Downgauging effects between 1960 and 1990 are thought to have contributed between 10 and 20% to the total reduction in materials consumption. This is a significant impact. This trend is however very difficult to assess, as the definition of autonomous developments is hardly feasible; for example car design changes in time and the average car size changes, so comparison of car weight in time is not straightforward. Instead of tonnes, a large number of other physical (engineering) characteristics must be studied for proper assessment of the impact of materials quality improvements, e.g. tensile strength. Only the example of steel will be discussed in order to show the extent of changes that occurred.

Steel consumption decreased because of [53]:
- Increasing yields due to technological changes at different stages of steel production and processing
- Increasing product control, resulting in decreased spread in product quality and increased design characteristics
- Improved product characteristics like tensile strength, based on new steel qualities
- Improved resistance to corrosion, based on improved coating
- Improved product design, eg honeycombed beams instead of full steel beams, prestressed concrete reinforcements instead of normal reinforcements
- Improved product design by CAD/CAM, systems optimisation etc.
- Increased product service per unit of steel product. Famous examples are electric locomotives vs. steam locomotives. In this case the process characteristics improved (electric engines have a much higher energy output per weight unit). Increase in average unit capacity is another very important cause for reduced materials demand. Both developments occur for many types of production equipment.

How important are these separate effects for the total steel consumption? This question has not yet been answered. A number of case studies are well known.

Reduced materials losses
The introduction of continuous casting, improved control of rolling and annealing, improved control of impurity contents in steel production and also improved materials yield in steel processing resulted in reduced materials losses. The gain is in the range of 20-30%.

Improved steel quality
High strength steel and coated sheet replaced carbon steel in many parts of cars, trucks and ships (saving 33%), new steel qualities were introduced in the beverage can market (saving 33%), the strength of steel reinforcements doubled (saving 50%). The examples are spectacular, the average saving is less extreme, because such large savings were not achieved for eg tubes and structural steel - the average saving is in the range of 20-30%.

Improved productivity of capital equipment
As machinery, industrial installations and transportation equipment are major steel applications, the increased productivity of this equipment transcends into reduced steel consumption. This increased productivity is caused by upscaling, increased service life of goods, smarter process routes, improved process control, computer aided manufacturing. The gain is in the range of 10-20%, resulting in a steel saving of 5-10%.

The resulting gain of these three trends has been between 50 and 75% - without these gains in the last three decades, the steel consumption would currently be two times to four times as high. Given the importance of steel production for the energy consumption of the whole industry, it may be clear that such savings are a main cause for the declining energy consumption in the basic metal industry.

4. ALUMINIUM PROCESS TECHNOLOGY

The primary aluminium production and aluminium recycling technology will be discussed separately in this chapter.

4.1 Aluminium production from bauxite

Four main processes can be distinguished in the primary aluminium production:
- extraction of alumina (Al_2O_3) from Bauxite ore
- anode production
- primary electrolysis and smelting of alumina to aluminium
- semi-fabrication of aluminium and aluminium alloy products by rolling, extrusion etc.

The overall chemical reaction can be written as:

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$$

The chemical reaction enthalpy ($\Delta G^0_{298,1\ atm.}$, the minimum amount of energy that is required for reduction of aluminium oxide to aluminium) is 29.2 GJ/t aluminium. It will be shown furtheron that the current practice requires substantially more energy, but the losses are to a large extent a consequence of the (electricity consuming) primary smelting process.

Bauxite, a tropical soil type with high aluminium content (approx. 50% Al_2O_3), is used as natural resource. Bauxite originates from mineral leaching by rainwater. Aluminium is the element that leaches as last one, resulting in weathered soils that are enriched in aluminium minerals. Alumina, Al_2O_3, is produced from bauxite. Alumina serves as feedstock for the electrolysis. The carbon anode is consumed in the process, so significant amounts of anodes are required. The semi-fabrication processes convert aluminum ingots into semi-finished products like sheets, wire, profiles etc. The five production steps will now be discussed separately.

Alumina extraction

Alumina (Al_2O_3) is at present exclusively produced from the mineral bauxite, which is found mainly in tropical countries. The alumina extraction process is in most cases located in the country where bauxite is found (due to lacking environmental constraints and high transportation costs). Alumina is extracted from bauxite by the Bayer process. The alumina is dissolved in hot caustic soda (NaOH), separated from the impurities, recrystallized as the hydrate and finally calcined (converted to the oxide) at 1200°C. On average, between 4 and 5 tonnes of bauxite is needed for 2 tonnes of alumina, from which 1 tonne of aluminium can be produced.

The energy use for bauxite mining, raw materials preparation and the Bayer process is approximately 25 GJ/tonne aluminium. There is still significant potential for improved energy efficiency in this part of the aluminium production chain.

Anode production

Cells operated with prebaked anodes now dominate the industry, as they have better anode carbon quality and do not emit tar fumes as the formerly used Söderberg anodes do. In addition, they significantly reduce carbon consumption. For this reason, only prebaked anodes will be discussed in more detail.

The carbon anodes are consumed in the Hall-Héroult process for primary aluminium melting at a rate of about 0.41 tonne carbon/tonne aluminium (net consumption, excluding anode residues) [54] and must be replenished. The theoretical minimum anode consumption is 0.334 t carbon/t aluminium [55]. They are usually produced from petroleum coke and pitch, which are ground and mixed to yield green anodes. These are baked at temperatures of 1100-1200°C. A description of the Aluchemie horizontal flue bake furnace can be found in [56]. The oven is heated by natural gas burners.

According to [54], the baking of the anodes consumes 2.3 GJ/tonne aluminium. The energy contents of the coke and pitch, which is about 14.4 GJ/tonne aluminium is not incorporated in these figures.

Care is required in comparison of different anode production technologies, because the anode quality may differ. Anode quality variations may influence the anode performance, which may cause significant problems in the operation of the primary aluminium smelters.

Primary smelting

Primary aluminium is obtained from alumina by the Hall-Héroult electrolytic smelting process. In this process, the pure alumina is continuously dissolved in a cell containing molten cryolite (Na_3AlF_6), through which an electric current is passed. Molten aluminium collects above the carbon (graphite) cathode, which lines the base of the cell, while oxygen is released at the carbon (prebaked) anode. Oxygen and the anode carbon react to produce CO_2. Pure cryolite has a melting point of 1012°C, but various additives, such as aluminium fluoride (AlF_3) and magnesium and lithium fluoride (MgF_2 and LiF_2), reduce the melting point of the electrolyte, allowing operation at 940-980°C. The main characteristics of the cell performance are shown in Table 4.1.

Table 4.1 *Primary aluminium cell performance [57]*

Operational parameter		1945	1995
Cell amperage	[kA]	25-50	175-300
Cell voltage	[V]	5.0	4.1
Current efficiency	[%]	80-85	92-95
Electricity consumption	[GJ/t Al]	72-90	46.8
Cell production	[t/year]	55	820
Cell operation		Manual	Automatic
Labour productivity	[t Al/worker]	7	200

The Hall-Héroult process was first introduced in 1886, so it is more than 100 years old. The process has reached its maturity stage. Gradual improvements are however still possible. Data in Table 4.1 show the significant improvements between 1945 and 1995. The size of the operation increased significantly, which resulted in increased energy efficiency and increased labour productivity. The Hall-Héroult process is very energy intensive. As the electricity costs are an important fraction of the total production costs, energy efficiency is since long a major area of research for aluminium industries. Total electricity use (excluding transformation losses) varies from 46.8 GJ/tonne aluminium for the state-of-the art plants up to more than 60 GJ/tonne (exceptionally high for old Russian Söderberg smelters, most Western plants around 48-49 GJ/t). The theoretical minimum energy requirement for aluminium electrolysis is at 980°C approximately 23 GJ/t aluminium, so a significant potential for improvements still remains.

Increased energy efficiency can be achieved by larger cells, continuous anodes, improved bath composition, improved cell feeding systems and improved alumina quality. The potential for additional electricity savings (compared to the state of the art plant) is probably in the range of 5-10%. No major breakthroughs are expected for the next 25 years that may reduce the energy consumption more significantly (see also Section 10).

Semi-fabrication operations

The semi-fabrication process can be divided in three groups:
- rolling
- extrusion
- casting.

Rolled products are produced by passing a suitable ingot at 500°C through a succession of rolling mills to obtain the required width and thickness of sheet metal. These hot rolling steps are mostly followed by cold rolling and annealing steps.

Extrusions are made by forcing cylindric billets at 450-570°C through a die of the required shape. A typical extrusion press uses a 2000 tonne thrust provided by electric driven pumps. Before rolling and extrusion, the aluminium ingots sometimes have to be remelted.

Cast products are manufactured by pouring molten metal into a mould. These moulds can be disposable and made of sand or permanent metal moulds. The metal can be forced in the mould under pressure or poured in under gravity.

Table 4.2 provides an energy balance of the primary aluminium production process.

Table 4.2 *Primary aluminium production energy balance [58]*

Process	Fuel [GJ/t Al]	Electricity[1] [GJ/t Al]	Final [GJ/t Al]	Primary[2] [GJ/t Al]
Alumina extraction	20.4	1.7	22.1	24.7
Electrolysis (incl. anodes)	23.0	48.0	71.0	143.0
Casting	1.8	0.0	1.8	1.8
Total	45.2	57.8	94.9	169.5

[1] Excluding transformation losses.
[2] Assuming 40% efficiency in electricity production.

Current electricity consumption is approximately 49 GJ/t Al for the Pechiney smelter and 54 GJ/t Al for the Aldel smelter. The planned renovation of the Aldel plant will probably reduce the specific electricity consumption.

4.2 Aluminium recycling

Secondary aluminium production is limited by the availability of aluminum scrap. The amount of aluminum scrap depends again on the amount of aluminium that is released from its application and the fraction that is recovered. The recovery is generally well established for large clean scrap parts, but not for small amounts of contaminated waste like packaging. For such waste catagories exists a significant potential for increased recovery, that is currently filled by improved separation technologies for aluminium from MSW (Municipal and Solid Waste).

Secondary refining

Aluminum is easily remelted because the smelting temperature is relatively low: 700-800°C. The energy requirement for refining aluminium scrap (expressed in primary energy equivalents) is only 5-10% of the energy requirement for the primary production process (depending on system boundaries and scrap quality).

A major constraint for aluminium recycling is the variation in alloy content and the content of impurities (water, oil, laquers etc.) in the recycled scrap. The scrap must be sorted by the refiner and blended to produce ingots of an acceptable alloy composition. It is difficult to remove alloying elements (except magnesium and zinc) from the scrap. Alloys for casting purposes contain higher amounts of (a number of) alloying elements and are thus more easily produced from scrap than wrought aluminium products.

The increasing diversity of aluminium alloys poses problems for the aluminium recycling, as separation of alloying compounds is problematic due to the aggressive nature of aluminium. It is possible to use Al1000 for other aluminium types, it is currently not possible to produce Al1000 out of the other aluminium types (see Appendix A). Contaminants can completely alter the material properties: e.g. lead concentrations of 0.05% result in an aluminium quality that is not suited for rolling. As long as the global aluminium consumption keeps growing rapidly, alloying elements and contaminants pose no problem. If the global aluminium demand will stabilise in coming decades, new recycling technologies are required in order to produce sufficient secondary aluminium that can be wrought. Problems in this respect are however not expected for the next 10-20 years. Emerging recycling technologies can solve problems in the period of rising alloy contents.

Table 4.3 divides the Dutch recycling companies according to the scrap quality that can be recycled. It is more or less evenly distributed among the three main scrap types.

Table 4.3 *Production of secondary aluminium [59]*

Waste type	No. companies	Capacity [kt pa]
Heavily polluted	4	53
Lightly polluted	2	51
Very lightly polluted	2	42
Unpolluted		pm
Total		146

Scrap which is heavily contaminated with e.g. paint causes significant toxic emissions from the melting furnaces. In recent years, the industry developed pyrolysis technology to remove organic contaminants from the aluminium scrap.

Scrap, which has a high surface/volume ratio (such as cans) tends to become oxidised during the melting resulting in significant metal loss. These losses range for gas-fired ovens from 3-8%, depending on the smelting period, the scrap particle size and the oven characteristics [60].

Several aluminium smelting oven types can be discerned. Their application depends generally on the scrap characteristics. Smelting methods are [61]:
1. direct charging to the furnace hearth
2. tower melters
3. flotation melters
4. induction furnaces
5. reverbatory melter with side-charge well
6. rotary-barrel furnace
7. plasma furnace.

Important oven types are the reverbatory smelter with side-charge well and, more recently, the tower smelter and the vertical flotation smelter (only suited for small particles). The sidewell oven consists of a large pool of liquid metal. The hot metal travels to the side-charge well where it meets the scrap. It loses its heat in the melting of the scrap and returns along with the newly melted metal back to the hearth for reheating. In tower melters, the scrap is preheated in a series of levels or holding areas where the exhaust gases from the burners pass on their way through, before it is introduced into the smelting bath. The vertical flotation smelter contains a heated conical chamber where the aluminium scrap melts before it is introduced into the bath. This system is only suited for light aluminium scrap particles because heavy scrap particles will not float in the conical chamber. For induction furnaces (heated by electricity), aluminium losses are significantly lower than for fossil fuel heated ovens: in the range of 1%. Because of the batch processing method and the limitations concerning contaminants, the induction ovens are however less popular.

Special attention deserves the treatment of slag. Salts are added to the smelt in order to separate other elements from the aluminium. This slag is chemical waste and contains significant amounts of aluminium that can be recovered. The slag is nowadays treated to produce secondary materials that can serve as input for eg cement production.

Table 4.4 provides an energy balance for the preparation of secondary aluminium from mixed scrap.

Table 4.4 *Secondary aluminium production energy balance [58]*

Process	Fuel [GJ/t Al]	Electricity [GJ/t Al]	Final [GJ/t Al]	Primary[1] [GJ/t Al]
Scrap preparation	0.0	0.4	0.4	1.0
Scrap melting	4.5	1.1	5.6	7.3
Slag treatment	2.2	0.3	2.5	3.0
Casting	1.8	0.0	1.8	1.8
Total	8.5	1.8	10.3	13.1

[1] Assuming 40% efficiency in electricity production.

5. ALUMINIUM COSTS AND REVENUES

The fact that a major part of the entire aluminium industry (including mining and refining) is controlled by a limited number of companies makes that specific information about e.g. prices of resources and investment costs in the production technology is not publicly available. Basically, the same processes for mining, refining and smelting are being used all over the world. Investment costs, however, depend on capacity of equipment, local circumstances, and whether it is a greenfield project or an expansion of current capacity.

The importance of the alumina costs in total operating costs explains the widespread vertical integration in the aluminum industry. If bauxite is mined and alumina is produced within the same company as the one which operates the aluminium smelter, significant cost reduction can be achieved (profit margins of intermediary trade can be smaller). The large fraction of expenses for energy in total operating costs, justifies a choice of location, at least for new primary smelting capacity, with either generally low electricity tariffs or preferential tariffs for the aluminium plant. Transport costs on the other hand seem to have a much smaller impact on operating costs. Typically, transport costs of alumina to the smelter range around 1.2% of total operating cost (min. 0.1%, max. 1.8%) [62].

Good data on business economics are scarce and often contradictory. The oligopolistic character of the industry has lead to convenants and agreements, both within the industry and between industry and governments. For economic assessments quantitative information is lacking due to confidentiality. Ongoing joint ventures and other forms of cooperation result in decreasing competition and reduced market forces. The analysis in this chapter should be considered in the light of these shortcomings.

The general cost structure is introduced in Paragraph 5.1 and is discussed in more detail in the following paragraphs. Capital costs are discussed in Paragraph 5.2, followed by the independent costs in Paragraph 5.3 and the utilization costs in Paragraph 5.4. Data from these four paragraphs are combined in Paragraph 5.5 to yield an overview of the cost and revenue structure for the Dutch aluminium industry.

5.1 General cost structure

In this study an attempt is made to assess costs and revenues for the primary and secondary aluminium industry in the Netherlands.

To analyze costs of the main aluminium production process, costs are subdivided into capital costs, independent costs and utilisation costs. These three categories are estimated for the base year 1992, since available statistical data are most complete for this year.

Concerning annualized capital, two types of costs are distinguished: interest on the capital and depreciation of the value of the installation. Capital costs are related to the following petrochemical investments:
- battery limit investments
- off sites (e.g. storage facilities, infrastructure, power generation equipment, housing)
- engineering costs
- spare parts
- contractor fees
- initial charges
- startup costs.

Independent costs are those that are neither capital nor utilization dependent costs. The main independent costs for the basic metal industry include labour costs, research and development costs, maintenance costs (buildings, land, installations), rent and leasing costs (building, land, machines and transport mediums).

As far utilisation costs are concerned in the steel and aluminium industry, the most important costs are raw material and energy costs and transport costs of outputs to the customer.

The general formula for annualised costs is:

$$COST = \frac{R}{1-(1+R)^{-N}} \times INV + FIX + VAR \times X$$

where:

COST	= Annualised costs		[NLG/year]
R	= Interest rate		[%/year]
N	= Technical life of the installation		[Year]
INV	= Investment		[NLG]
FIX	= Independent costs (e.g.labour)		[NLG/year]
VAR	= Utilisation costs (e.g. energy, raw materials, anodes)		[NLG/t]
X	= Output		[t/year]

X is determined by the production capacity of the investment and a utilization factor. This correction is applied because plants are temporarily shut down for maintenance or because they operate below their maximum capacity. The utilisation factor in primary aluminium plants is generally high due to the high capital cost and the technical constraints (in the range of 0.90-0.95).

The first term in this formula is based on a constant cash flow for interest and depreciation that results from an annuity. The real discount rate is the discount rate after correction for inflation.

Proper assessment of project costs requires careful and detailed analysis. Especially system boundaries deserve attention. Cost structures of aluminium projects are often dominated by other costs than battery limit investments. Especially projects at remote locations require often significant additional investments in infrastructure (harbours, roads) that are essential for proper assessment. This is one important reason why plants in developing countries cost more than similar plants in industrialised countries [63]. Other differences occur e.g. for the required amount of spare parts, backup facilities, environmental control equipment, the number of employees, etc. In developing countries, costs of plants are 35-150% higher than plants in industrialised countries with similar outputs. Differences are smaller between industrialised countries, but the differences can still be significant. It is important to remark that costs are estimated with data providing from different sources e.g annual reports, national statistics and business literature. These different sources are used since national statistics do not provide separate data for the aluminium industry.

A first general quantification of costs in the aluminium chain is shown in Figure 5.1. It is a cost analysis for an aluminium window frame. The figure shows that the main costs occur at the end of the chain, while the main energy consumption occurs at the beginning of the chain. This is an important observation because financial considerations dominate energy considerations. It is also important to note that labour costs become more important in the second half of the chain. While competition in the first half will be dominated by costs of labour and electricity, competition in the second half will be dominated by labour costs only. The aggregated costs of the total chain of aluminium are composed of 59% labour costs, 10% energy and materials input costs and 31% capital, transportation and other costs.

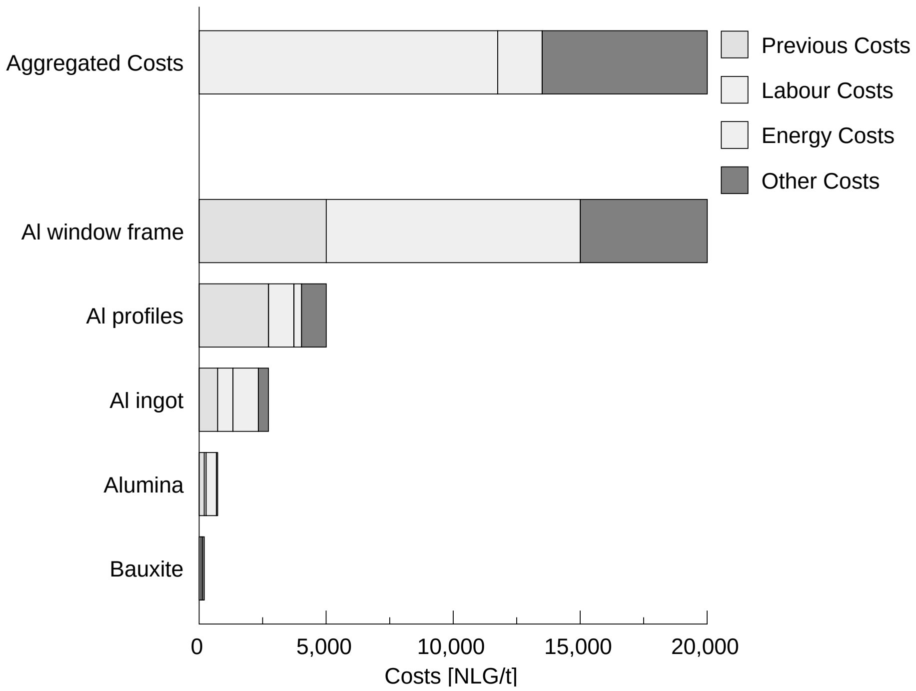

Figure 5.1 *Cost structure in the aluminium chain*

The prices in the aluminium chain are further illustrated in Table 5.1. Aluminium ingots costs approximately 2500 NLG/t, semi-finished products cost 2-3 times as much, while finished products cost 6-8 times as much.

Table 5.1 *Dutch export prices of different aluminium products, 1993*

SITC code	Product	Price [NLG/t]
Ingots		
760110000	Crude aluminium	2451
760120100	Primary aluminium alloys, crude	2552
760120900	Secondary aluminium alloys, crude	2474
Semi-finished products		
760410900	Aluminium profiles	8646
760429900	Other profiles aluminium alloys	6425
760521000	Aluminium alloy wire, d>7 mm	7516
760612500	Aluminium alloy strip	6170
760612910	Aluminium alloy strips 0.2<d<3 mm	4108
760720100	Aluminium sheet, d<0.021 mm	7149
Finished products		
761010000	Aluminium doors and frames	17290
761090900	Structural aluminium	14536
761290990	Reservoirs	16437
761510900	Other kitchen utensils	19662

The costs analysis is complicated by the unstable prices of raw materials and products and the fluctuations of exchange rates. Figure 5.2 shows that aluminium prices decreased significantly in real terms in the period 1960-1990. The decrease in guilders is even more extreme than the decrease in US$: real prices decreased by 60% between 1960 and 1990.

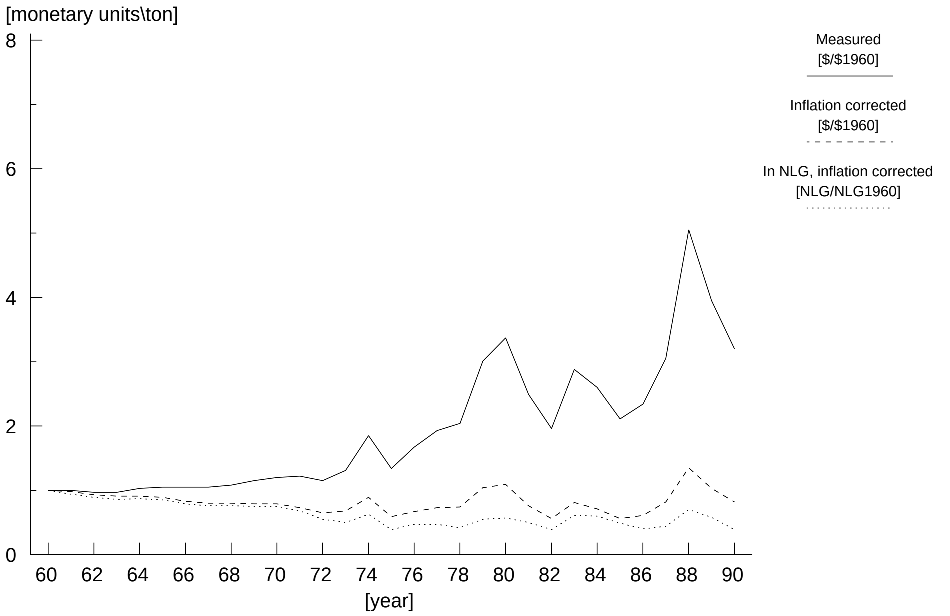

Figure 5.2 *Aluminium price trends 1960-1990 (1960=1)*

Note that the deflator in Figure 5.2 is based on the inflation correction for consumer prices. The deflator for producer prices is less extreme, resulting in less significant price reductions in real terms.

Even on the shorter term, prices in the aluminium industry can fluctuate substantially. This is shown in Figure 5.3. Prices decreased by 50% in the period 1989-1993. There is a clear relation between alumina, aluminium and scrap prices. The price difference between primary aluminium, aluminium alloys and secondary aluminum is remarkably small.

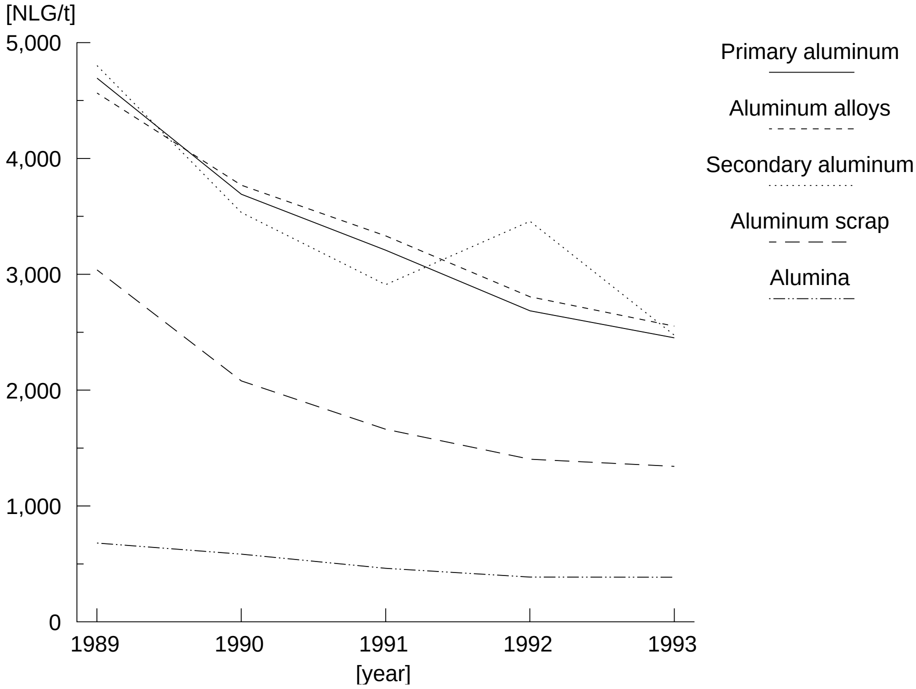

Figure 5.3 *Short term price changes in the aluminium chain, period 1989-1993 [64]*

The long-term price decrease for both aluminium and steel can be contributed to technological progress: labour, capital and energy intensity of both metals decreased because of economies of scale, new processes and increased energy efficiency. In both cases, natural resource prices remained the same or decreased even in real terms. For both metals, resource availability poses no problem in the next 25-50 years. As a consequence, prices may further decrease (assuming constant labour and capital costs). This trend would result in increasing material and energy intensity of production. In practice, this trend is to some extent off-set by the increasing product quality (a shift towards products with significantly higher added value).

Finally, some attention should be paid to the impact of exchange rates on the comparison of different production locations. Exchange rate fluctuations decreased in recent years the competitive position of Dutch producers, as the guilder rose substantially compared to most foreign currencies (Figure 5.4). This trend may however be reversed after the introduction of the European monetary union.

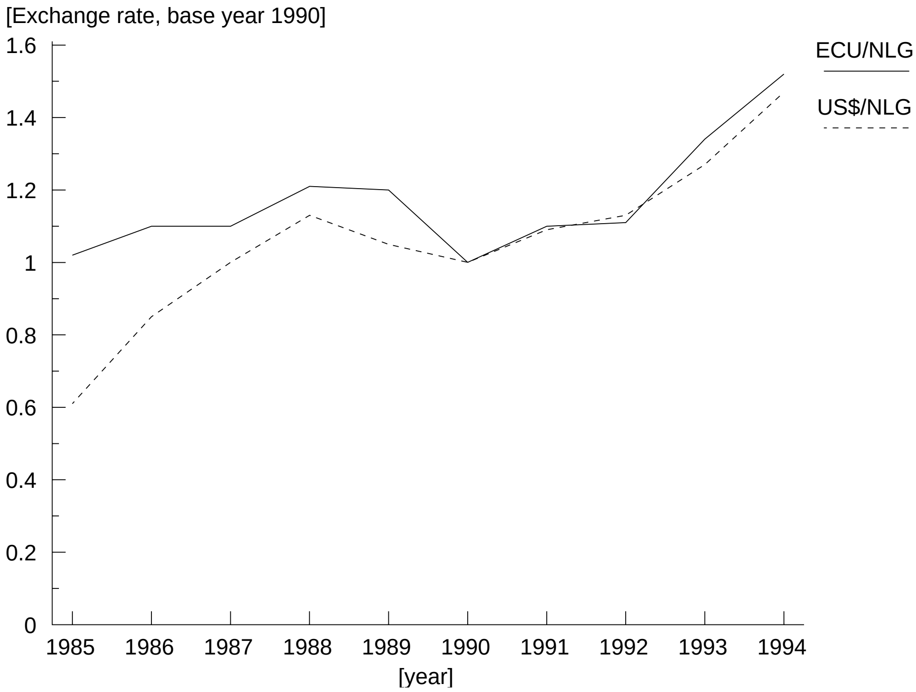

Figure 5.4 *Exchange rates fluctuations (1990=1)*

5.2 Capital costs

The aluminium industry is considered as capital intensive. Significant capital costs in the aluminium industry occur for the primary smelters and the anode production. The secondary production and aluminium processing are less capital intensive. Two distinct approaches can be used to estimate capital costs. First they can be assessed on the basis of total depreciations of the value of the installation. The second approach is to calculate capital costs from the total of yearly investments.

In this study capital costs have been estimated by calculating the depreciation value and interest since investment costs in aluminium production do vary significantly over the years. This interrupted growth is explained by the dominant investments in large production units with long life. In general, compared to the long life time of aluminium plants, the investments are rapidly depreciated. The depreciation period corresponds approximately to 12 years whereas the lifetime is approximately 25 years.

An IISI publication of 1993 [62] provides ranges for investment costs for mining, refining and smelting plants for locations in developed and developing countries (Table 5.2). The low end of the range represents developed countries, the high end represents developing countries. These cost estimates are originally based on a World Bank publication from 1980. It is thought that the investments costs decreased significantly in the last two decades. For example, the investment costs for the 60 kt expansion of the Alusuisse smelter on Iceland amounted to 5000 NLG/t aluminium capacity [65].

Table 5.2 *Investment costs for primary aluminium production*

	[NLG/t capacity]	[%]
Bauxite mining	750-950	6
Alumina refining	3000-5750	30
Aluminium smelting	7250-10750	64
Total cost	11000-17500	100

Capital costs for a new 250 kt primary aluminium smelter in the Netherlands (excluding anode production) are assumed to be the range of 1 billion NLG. Assuming a real interest rate of 5% and 3% inflation, a depreciation in 25 years and a utilisation rate of 90%, the capital costs are 400 NLG per tonne aluminium. Capital costs for secondary aluminium production are estimated to be 2000 NLG per tonne annual production capacity (based on [66]). Taking the same assumptions into account, capital costs amount to 200 NLG per tonne aluminium.

5.3 Independent costs

Independent costs are defined as annual costs that are neither investment related nor utilization costs. They occur independent of the degree of utilization of production plants. Independent costs are for example costs of maintenance of installations, labour, insurances and taxes. Attention will be paid to independent costs that have an important share in total costs, especially labour costs.

5.3.1 Labour costs

In relation to invested capital and revenues, employment in the aluminium industry is small. For a primary aluminium plant, the amount of employees is in the range of 5 per kt aluminium (see Table 4.1). This excludes the overhead etc. The overhead labour expenditures are estimated to be 50% of the direct labour expenditures. Assuming average labour costs (including direct and indirect costs) in the range of 80,000 NLG per employee per year (the average for SBI 27, [67]), total labour costs are 600 NLG per tonne aluminium.

5.3.2 Other independent costs

Other independent costs with importance in the aluminium industry refer to:

- *Maintenance and repair*
  Costs of maintenance and repair refer to buildings, terrains, machines and installations. These costs represent less than 5% of total costs.
- *Rent and leasing*
  These costs relate to the rent and leasing costs of buildings, land, machines and installations and transport equipment.

- *Payments to holding companies*
  They include for example service and administration costs made by the mother industry. They are neglected in the analysis.
- *Other operating expenses*
  These include marketing- insurance- communication- travelling- and administrative expenses as well as materials and appliances not directly used for production.

5.4 Utilization costs

Utilization costs in the primary aluminium industry refer to a large extent to energy and energy feedstocks for the production process, alumina costs, anodes and transportation of outputs to the customer. For secondary aluminium production, scrap costs are the main utilization costs. These utilization costs with a relative important share of total costs are discussed separately in this paragraph.

5.4.1 Energy costs

The aluminium industry is considered an energy-intensive industrial branch. The primary aluminium producers have separate, confidential contracts with the SEP concerning their electricity prices. Their price is lower than for the largest other electricity consumers. Their gas price is thought to be in the range of 15-20 NLG cents per m^3 [68]. Assuming they are linked to the middle voltage electricity net, their electricity price is thought to be 7-8 NLG cents per kWh (The price for aluminium processors is significantly higher, in the range of 12 NLG cents per kWh) [69]. Their electricity consumption (including losses for transformation) is thought to be in the range of 50 GJ/t Al. The energy costs amount thus to 975-1110 NLG/t Al (excluding anodes).

5.4.2 Anode production costs

The anode production costs (including raw materials, assuming 300 NLG/t petcoke) are thought to be in the range of 600-700 NLG per tonne of anodes [56]. The anode consumption (including residual anode) is in the range of 0.5 t/t Al, so the anode costs are 300-350 NLG per tonne aluminium.

5.4.3 Alumina costs

Alumina costs can be derived from national trade balances. Table 5.1 shows developments in alumina import prices in the period 1989-1993.

Table 5.3 *Developments in alumina prices [70]*

	[NLG/t alumina]	[NLG/t aluminium]
1989	679	1290
1990	583	1108
1991	461	876
1992	385	732
1993	384	730

Table 5.3 shows that alumina costs (Dutch import prices) were significantly reduced in the period 1989-1993. This decrease was proportional to the decrease in aluminium prices, shown in Figure 5.3. The price decrease can be explained by the decreasing exchange rate of the US$ (see Figure 5.4). The decreasing aluminium prices in the same period suggest a relation between alumina and aluminium prices.

5.4.4 Aluminium scrap costs

Scrap costs are closely related to the price for aluminium alloys. The difference is accounted for by the aluminium scrap transportation, upgrading and smelting costs. The upgrading process expenditures are determined by the scrap quality. The aluminium yield differs to a large extent for different scrap qualities (see Table 5.4). It is thus no surprise that scrap prices differ. Table 5.4 provides some insight in the price range. The price difference is almost a factor 2. Because of lacking clear international definitions, the price of scrap is determined per shipment. Aluminium scrap is internationally often classified according to the NARI standards (National Association of Recycling Industries).

Table 5.4 *Scrap prices dependence on scrap quality (october 1995 situation) [71]*

Scrap type	Price [NLG/t scrap]	Yield [%]
Pure cuttings	1960	95
Old mixed scrap	1470	80
Commercial cast	1580	85
Alloy turnings	1130	70

5.4.5 Transportation costs

Aluminium is transported by several means of transport; by trains, trucks and ships. A first general division can be made into intercontinental and long range transportation (seaborne) and transportation to and from surrounding countries. Each option will be discussed in more detail.

Seaborne transportation

Transportation of bulk commodities, semi-finished products and finished products must be considered separately, as the transportation, loading/unloading and storage practice differs. As a consequence, transportation costs differ to a large extent.

Iron ore, metallurgical coal and bauxite/alumina trade constitute almost half of the world seaborne trade in bulk dry commodities (Table 5.5). There exists also a clearly growing trend in both steel and aluminium raw material shipments.

Table 5.5 *World seaborne trade in main dry bulk commodities, 1990 [72]*

	Amount [Mt pa]	Fraction [%]
Iron ore	358	30
Metallurgical coal	175	15
Bauxite/alumina	50	4
Other	608	51
Total	1191	100

The current price for a Capesize vessel (80-160 kt freight capacity, the main ship type) is around 25,000 NLG per day. This is the 1990/1991 price in a balanced market situation. Assuming an average load of 80 kt, the price per tonne per day is 0.3 NLG. The price for loading and unloading the vessel is not included in these prices. Assuming transportation distances in the range of 14-28 days and a doubling of the transportation costs because of loading/unloading and harbour fees, transportation costs are in the range of 8-17 NLG per tonne. These figures are in the range that is quoted in other sources for dry commodity transportation, see Table 5.6.

Table 5.6 *Price indications for deepsea commodity transport (2nd quarter 1996) [73]*

Type	Freight size [t]	Route	Rate [NLG/t]
Steel	25,000	Black Sea/China	61
Coal	150,000	Australia/Rotterdam	10.2
Scrap	35,000	USNH/South Korea	56
na	30,000	Trans Atlantic	13
Iron Ore	125,000	Narvik/Rotterdam	4.3
Iron Ore	na	Brazil/Rotterdam	9
Iron Ore	110,000	Narvik/Dunkirk	5.7

One should add that prices can differ on routes where no proper return freight can be found. There is also a significant fluctuation in freight prices due to market conditions.

Another important type of seaborne transportation is intercontinental container freight. Freight rates for container transportation are shown in Table 5.7.

Table 5.7 *Freight rates for containers 1st quarter 1996 [74]*

Route	Cost [NLG/TEU][1]	Cost [NLG/t]
Europe/Asia EB	2075	150
Europe/US WB	2350	170
Asia/US EB	2970	210
Asia/Europe WB	2330	165
US/Europe EB	2520	180
US/Asia WB	2275	165

[1] TEU = Twenty-feet Equivalent Units (14 t maximum content)
[2] WB = West Bound; EB = East Bound

Freight rates for containers are significantly higher than for commodities. The main advantage is off course the possibility to transport more fragile products. Products which require less care like ingots, steel tubes, sheet, coils etc. can probably be exported without containers. Their transportation costs are in between the costs for bulk commodities and for containers.

Road, Rail and inland shipping

The comparison of transportation tariffs concentrates on the Dutch-German region since the major part of Dutch aluminium products are exported to Germany.

For goods that are being transported from Rotterdam to several German destinations a comparison is shown for the three kinds of transport. Destinations have been translated in to kilometers (Figure 5.5). These tariffs for container transport include:
- the transfer of goods from the Dutch quays on to the ship
- the main transport to the customer
- the transfer on German quays or platforms
- the transport to the final destination.

The weight in a container is limited by the maximum weight for a container haulage truck (40 tonnes in Germany, 11 tonnes dead weight). The maximum load for a 40 foot container is for Germany thus limited to 29 tonnes.

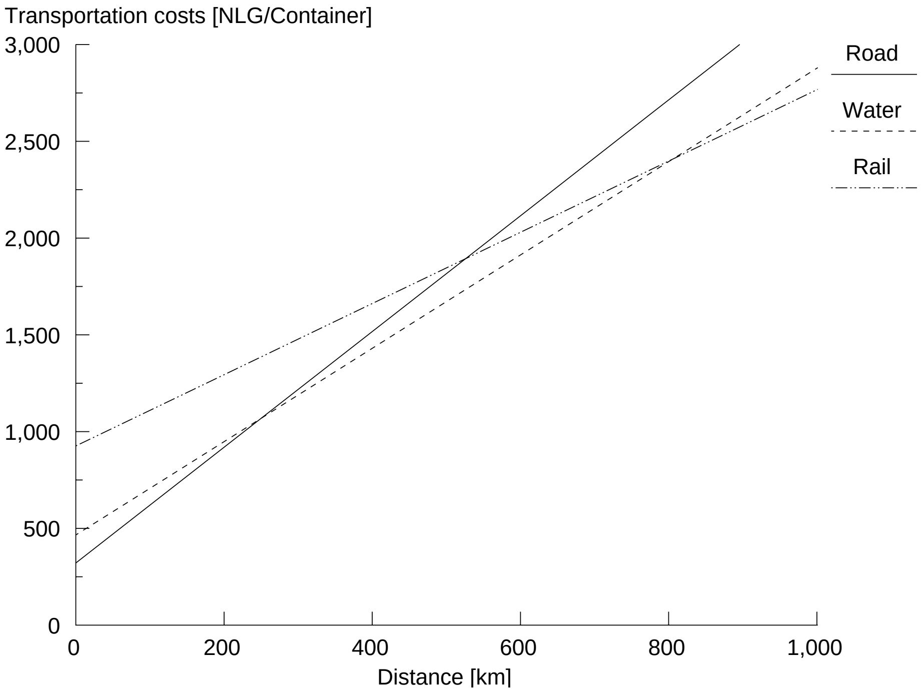

Figure 5.5 *Transport tariffs for road, rail and inland container shipping (40'/29 tonnes container, no return freight) [75]*

Figure 5.5 shows that the graph for road transport is steeper than the two other modes and transport by rail is more costly than by ship. Break even distances for road transport versus the other modes lie between 300 an 700 km, but depend on available infrastructure. For nearby destinations road transport is the cheapest solution. The relatively cheap kilometer costs of rail or river transport do not compensate the extra costs of transfer that can be saved in the case of road transport. Meanwhile river transportation is the cheapest option for middle range distances that are situated near waterways. For the southern German destinations remote from the river and a long way from Rotterdam, the rail option is favourite. The preceding analysis includes however no transportation time considerations: road transportation is often favoured because of just-in-time delivery policies.

Furthermore Figure 5.5 shows that transport costs for the three transport modes do not significantly differ from each other. Assuming that the average distances are between 400 km and 600 km and that the average utilization degree of a container is 70%, transport costs are estimated to be 55 NLG/ton.

These data refer off course only to container transportation. Important amounts of aluminium are transported on pallets without container. The transportation costs for pallets are per weight unit lower than the transportation costs for containers.

Total transportation costs in the Dutch aluminium industry

These costs do not completely appear in the value of shipments of the basic metal industry. For exports, fob prices are used in trade statistics and buyers of aluminium have their own transport facilities. 50% of the total transportation costs are attributed to the Dutch basic metal industry. Future infrastructural transport programs can influence the transportation costs. The importance of this impact is however still unclear.

5.5 Revenues

In Table 5.8 revenues of the aluminium industry are estimated for the year 1992. Calculations are based on prices of aluminium products from chapter 5, product flows in Table 3.1 and net export values and national consumption data in Figure 2.1. The data refer to the total Dutch aluminium industry. Intra-industrial sales (eg anodes from Aluchemie to Aldel or Pechiney) are not considered in these figures. The price for profiles and sheet includes only the added value, as the primary and secondary production of aluminium are separately accounted. The total revenues, 2.8 billion Dutch guilders, represent 0.85% of the total industrial production value of 330 billion guilders.

Table 5.8 *Estimation of revenues in the aluminium industry, 1992*

	Production [MT]	Prices [NLG/T]	Revenues [10^6 NLG]
Primary aluminium ingots	0.23	3000	690
Secondary aluminium alloys	0.15	3500	525
Anodes (surplus)	0.31	650	200
Sheet/profiles (est.)	0.35	4000	1400
Total Revenues			2810

5.6 Summary of the cost and revenues in the Netherlands

Figure 5.6 shows a summary of the cost structure in the primary and secondary aluminium industry, based on the analysis in Paragraph 5.2 - 5.5 (see also Table 5.9 for the actual figures). Raw materials represent the alumina, anode and scrap costs, respectively. Other costs include maintenance and repair costs, rent and leasing costs, research and development costs, payments to holding companies, taxes and sale costs. Figure 5.6 shows that energy costs make up a major part of total costs in the primary aluminium industry. In the dutch situation, 70% of the costs are utilisation costs (energy, anode, raw materials and transportation costs). Labour costs represent 18% of the total costs, while capital costs represent 12% of total expenditures. As aluminium prices tend to decline (Figure 5.2), a renewed investment decision in a primary aluminium smelter differs from a national point of view from the investment decision 30 years ago, as the added value declined significantly. The attractiveness of electricity price subsidies for primary aluminium producers will further decline in coming years. Because aluminium is an internationally traded commodity and scrap recycling is still increasing, it is possible to reduce primary aluminium production without harming the other industries that depend on aluminium supply.

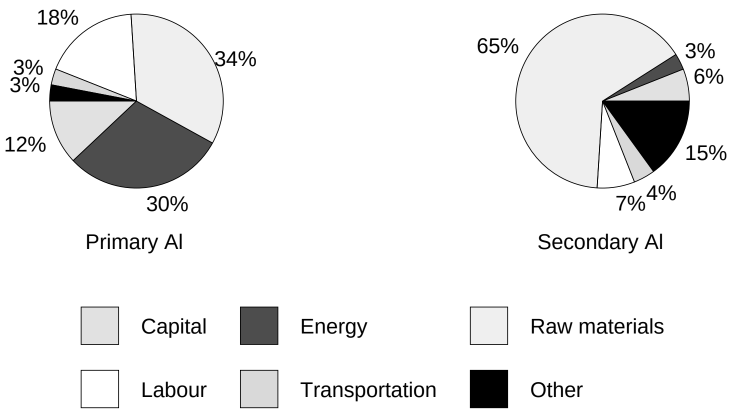

Figure 5.6 *Cost structure in the Dutch primary and secondary aluminium industry, 1994*

Table 5.9 *Costs and Revenues in the Dutch aluminium industry, 1993/1994*

Costs	Primary ingot [NLG/t Al]	Secondary ingot [NLG/t Al]
Alumina (5.4.3)	730	-
Electricity for primary smelting (5.4.1)	1000	50
Energy use for other processes (5.4.1)	25	35
Anodes (5.4.2)	350	-
Scrap	-	1800
Labour costs (5.3.1)	600	200
Capital	400	200
Other raw materials [1]	50	pm
Other costs (5.3.2) (includes transportation (5.4.5))	200	500
Total Costs	3355	2785
Total Revenues (figure 5.3)	3000	3000
Net Profits	-355	215

[1] Includes AlF_3 etc.

Costs and revenues are aggregated in Table 5.9. The difference in profitability for primary aluminium production and for secondary aluminium production is considerable. The figures indicate profitable secondary production, while the primary production generated losses. This can be explained by the low prices for primary aluminium in recent years (see Figure 5.3). The primary aluminium producers have a large fraction fixed costs that cannot significantly be reduced. Moreover, production can not significantly be reduced for individual plants. As a consequence, low aluminium prices result in losses. The secondary aluminium industry is apparently less affected by these fluctuations, because low prices can more easily be transferred to the scrap suppliers. Because scrap prices constitute a major part of the production costs, reduced scrap costs will significantly reduce the production costs. Moreover, the production volumes can be more easily adjusted, resulting in a more flexible reaction to market conditions.

Because electricity prices are fixed in long term contracts, the primary aluminium industry has much lower flexibility in this respect (only alumina prices can be decreased). In conclusion, secondary production meets favourable conditions in Western Europe, but is limited by scrap availability. Primary production depends on low electricity costs and cheap alumina supply; both are not certain in the Netherlands on the longer term.

6. STEEL PROCESS TECHNOLOGY

This chapter discusses the process technology for primary steel production in blast furnaces and steel recycling in electric arc furnaces. The production processes and their net primary energy consumption are shown in Figure 6.1.

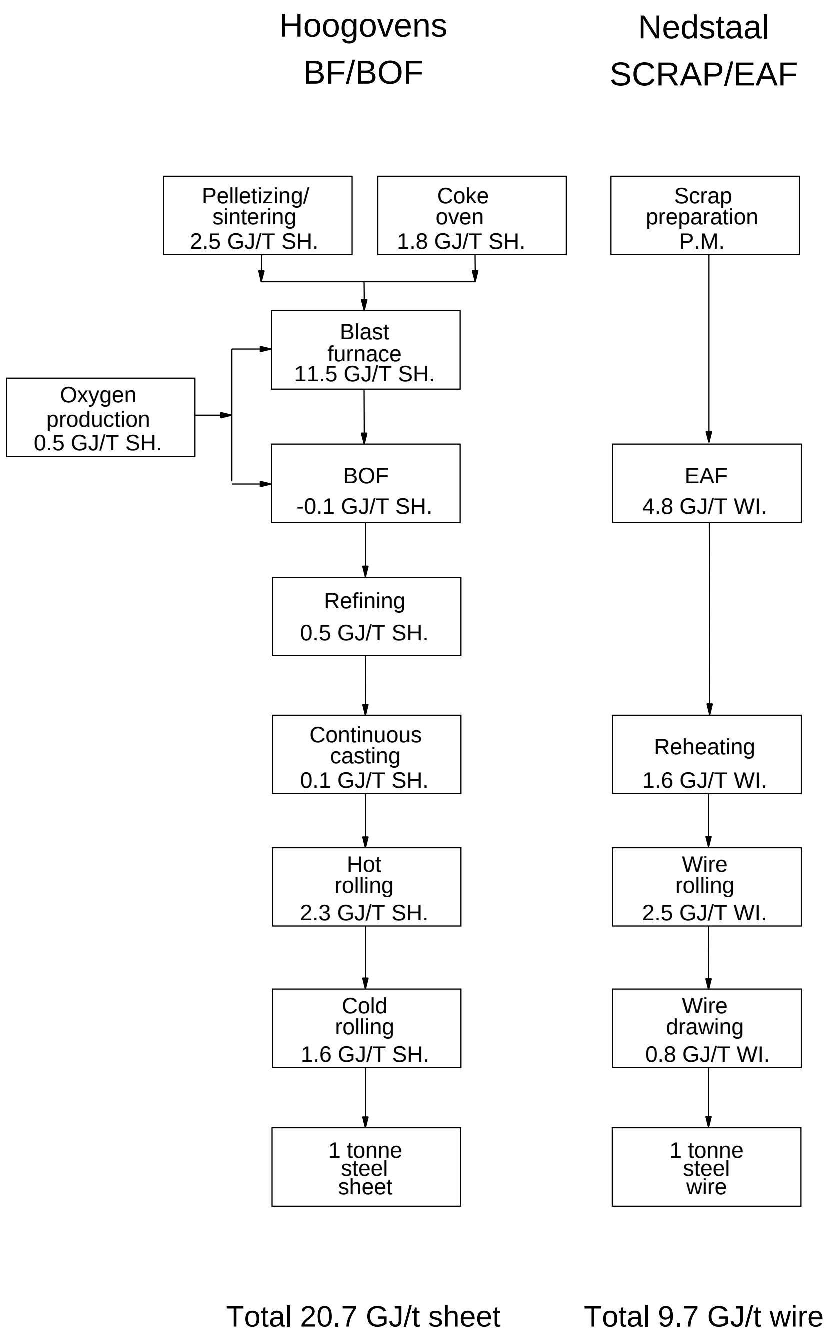

Figure 6.1 *Steel production processes in the Netherlands [76,77,78]*

Two process routes exist: the primary steel production in blast furnaces (like Hoogovens) and the secondary steel production in Electric Arc Furnaces (like Nedstaal). Both will be discussed separately in paragraph 6.1 and 6.2, respectively.

6.1 Blast furnace steel production from ore

The steel making process consists of five main steps that will be discussed separately:
- production of blast furnace inputs
- pig iron production
- crude steel production
- steel forming
- steel rolling.

The overall chemical reaction can be written as:

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

$$Fe_3O_4 + 4CO \rightarrow 3Fe + 4CO_2$$

The carbon monoxide (CO) is produced by partial oxydation of coke and coal. The coke is essential in the process because it ensures the loose packing of the blast furnace, so the gases can flow upwards (a blast furnace is essentially a countercurrent flow reactor). Two types of iron ore can be distinguished: Fe_2O_3 (Haematite, of sedimentary origin) and Fe_3O_4 (Magnetite, of volcanic origin). The minimum amount of reducing agent for iron (Fe production) depends on the ore type: 6.7 GJ/t Fe for Haematite, 7.3 GJ/t for Magnetite ($\Delta H_{298,1\ bar}$). Haematite is however by far the most important iron ore type. Magnetite will not be considered any further.

Raw material preparation

For the production of pig iron in a blast furnace two main raw materials are needed: iron ore and coke. For more efficient production in the blast furnace the ore can be prepared by converting it to sinter or pellets. Sintering and palletising are processes that are linked to the current resource situation, where fine iron ores dominate. These ores cannot be fed into the blast furnace unless they are agglomerated. During the sintering process a mixture of ore, fine coke and other additives is brought in a semi-fluid state for a short period of time. This results in a homogeneous product (sinter), which is broken into small pieces and screened. In the alternative process of palletising the ore is finely ground with additives in a wet condition. The pellets are formed with a binder and dried. The combination of sinters and pellets is called agglomerate. Sinter (4.1 Mt pa) and pellets (4.1 Mt pa) are produced at the Hoogovens site in IJmuiden.

Coke is produced by batch pyrolysis of coking coal at temperatures above 1000°C for 16-20 hours. The thermal cracking yields a solid fraction (coke) and a gaseous fraction (coke oven gas). Coke is cooled by addition of water. 1 tonne of coking coal (32.6 GJ) yields 22.1 GJ coke and 350 m^3

gas (8.2 GJ). The gas is separated into tar, BTX (Benzene, Toluene, Xylenes) and coke oven gas. Tar and BTX represent together 1.9 GJ/t coal. Significant amounts of coke oven gas are used for the heating of the oven. The surplus gas (1.6 GJ/t coal) is used for furnace heating and for power generation. Apart from thermal energy, a coke oven uses 0.15 GJ electric energy/t coal. The over-all thermal energy efficiency of the coke oven is approximately 80%. The coke production is a costly operation because a number of toxic compounds (PAH, ammonia) are produced that require special treatment.

Pig iron production

Pig iron is mainly produced in blast furnaces. Agglomerate, limestone and coke are fed into the top of the furnace shaft; heated air (1450°C, 5.5 bar) is blown into the bottom of the furnace shaft; many steel producers blow also some coal or oil in the bottom of the furnace to reduce to quantity of coke needed; carbon monoxide is produced from the reaction of the oxygen in the air and the coke; the iron oxide is heated and partially reduced by the hot carbon and carbon monoxide to form lower oxides of iron; as the charge descends through the furnace, further heating and reduction occurs and molten iron and slag are produced; the molten iron and slag are tapped from the furnace hearth; the molten iron is transported in ladles or cars to the steel making furnaces to be refined into steel. The emitted blast furnace gas containing carbon monoxide can be used for other energy purposes and there is a possibility of electricity production from the exhaust pressure of the blast furnace gas. Recently, more and more coal or oil is injected directly in the blast furnace. This reduces the energy lost in the coke production.

In the near future some new production processes will become commercial, especially for replacement of the coke based blast furnace technology. They are discussed in more detail in Chapter 10.

Crude steel production

In the steel production process impurities like carbon, silicon, manganese, phosphorus and sulphur are partially or entirely oxidised and removed in the form of slag. Other elements, including nickel, chromium and molybdenum may be added to achieve certain mechanical or corrosion properties. The steel production is a key step: the batch is here already allocated to a certain client.

At the moment most steel is produced in basic oxygen furnaces (BOF, also called oxygen convertors) where the carbon in the pig iron feed is oxidised by injection of pure oxygen.

Scrap is used in conventional basic oxygen furnaces to act as a temperature moderator and to reduce the amount of pig iron that is needed (scrap is cheaper than pig iron). Approximately 10-15% scrap is added in the BOF process.

Because the carbon in the crude iron is oxidised, the process used to be a net energy source. Despite significant improvements in recent years in the steel production plant, there is a tendency towards increased energy consumption because the increased product quality standards require additional handling and result in more rejects. The vacuum pan oven is added, where the steel is treated with argon to remove impurities. The tendency towards products with very low carbon content requires also additional energy.

Steel casting

In the modern continuous casting, the molten steel is directly cast into semi-finished shapes (slabs, blooms and billets). The continuous casting method has many advantages over the ingot casting; it saves work, capital investments and energy. It results also in a significant reduction of materials losses.

Steel forming

During rolling, the semi-finished forms are transformed to flat strips or other shapes. Depending on the form and the required material quality only hot rolling or a combination of hot and cold rolling is applied. In the hot rolling process, the thickness is reduced from 200 mm to 1.5-25 mm. Hot rolling takes place at temperatures of 560°C, cold rolling at 30-40°C. The choice of rolling technology influences the steel crystal structure and thus the steel quality. A relative new practice is direct rolling. This means that the semi-finished products are transferred directly to the rolling mill. Energy can be saved because less energy is needed for reheating. After cold rolling, the steel mostly needs a heat treatment for recrystallising the deformation incurred by cold rolling, which improves the metal ductility. The most common form of heat treatment is annealing, in which the steel product is heated to temperatures between 650 and 950°C and subsequently slowly cooled.

Hot and cold rolling are techniques to produce strips, sheets and bars. Other products require other processes. In case of wire production, drawing is required. For tinplate products, a tinmill is required. For zinc coated sheets, a zinc bath is added. The energy requirement of finished products depends to some extent on the combination of forming processes.

The energy content of different semi-finished products is shown in Table 6.1. The energy content of coated products depends also on the energy content of the coating. The figures show a range in energy intensity. The energy content of coatings is not considered in Table 6.1, because this energy is consumed elsewhere. The contribution depends on the thickness of the coating. The energy content of coatings is in the range of 25-100 GJ/t. Assuming a coating weight fraction of 5%, the energy content of the product increases from 0 to 4 GJ/t (GER value, the energy consumption does not occur at the steel plant site).

Table 6.1 *Specific energy consumption for different products at Hoogovens ([10,76], adjusted)*

Product	Fuel [GJ/t]	Electricity [GJ/t]	Coating [GJ/t]	SEC [GJ/t]
Cast steel slabs	14.6	0.4	-	15.6
Hot rolled strip/coil	16.4	0.8	-	18.4
Cold rolled sheet/coil	17.5	1.3	-	20.7
Tinplate	18.2	1.8	pm	22.7
Zinc coated plate	na	na	pm	23.5e
Paint coated plate	na	na	pm	24.0e

[1] na = not available
e = estimated

The electricity consumption for hot rolling and cold rolling depends on the thickness of the rolled product. Figure 6.2 shows the power consumption for hot rolling and cold rolling of AISI 1015 steel as function of the thickness of the product. The initial thickness for hot rolling was assumed to be 20 cm, for cold rolling it was assumed to be 1 cm.

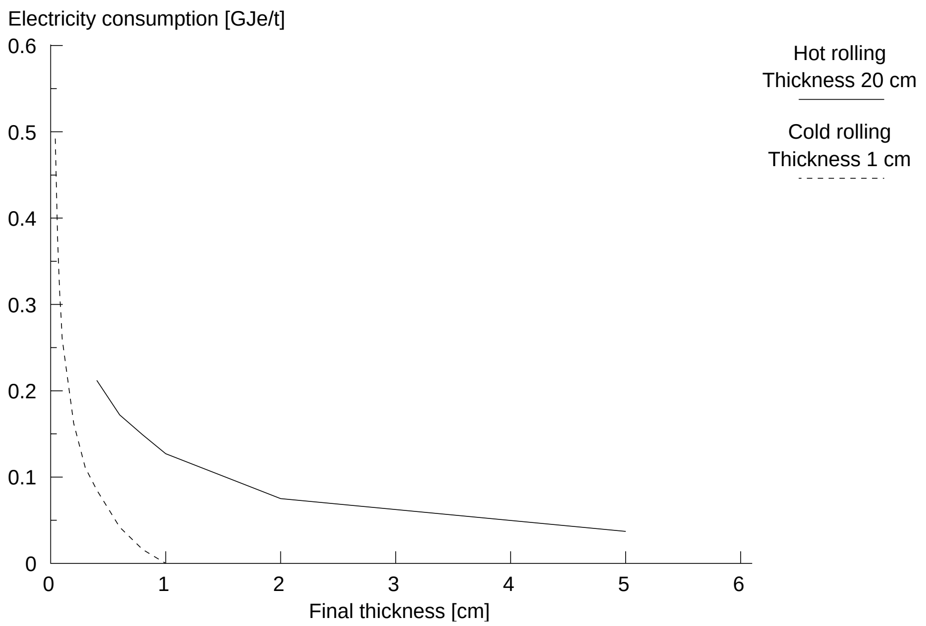

Figure 6.2 *Electricity requirement for rolling as function of the sheet product thickness [79]*

The figures in Table 6.1 show that the difference between steel slabs (the most simple product) and zinc coated and paint coated sheet is 7.1 GJ/t, a difference of 42% relative to the energy content of steel slabs. As a consequence, the trend towards steel products with higher added value (especially coated sheet) can increase the energy intensity of the product mix and can potentially outweigh the savings due to process improvements.

6.2 Electric Arc Furnace steel production from scrap

The second important steel production method is the electric arc furnace which is generally fed with scrap or sponge iron. EAF technology is gradually improving and many kinds of steel qualities can nowadays be produced.

The EAF consists of a cylindrical refractory lined vessel with a diameter to height ratio of 4 to 6. Three electrodes provide the electric arc for melting the scrap. The molten steel is tapped by tilting the vessel or by eccentric bottom tapping.

The power consumption for an advanced EAF with scrap preheating using off-gases is approximately 1.4 GJ_e, i.e. 3.5 GJ primary energy if an efficiency of electricity production of 40% is assumed. This does not include the scrap pretreatment and the subsequent rolling mills [80]. Table 6.2 shows an energy balance for two scrap smelting furnaces with a capacity of 350 kt per year. The EAF furnace with scrap preheat can be considered as current state-of-the-art smelting process. There exist however considerable efficiencies of scale. An EAF twice this size consumes approximately 0.36 GJ less (final) energy. The Contiarc process that is also shown in Table 6.2 is a new process with a higher energy efficiency [81]. The increased efficiency is achieved through improved use of the sensible heat of the off-gases and the reduced energy losses. These improvements are achieved with a completely new oven design with continuous scrap charging and improved preheat. Power consumption is 0.6 GJ_e/t lower for this continuous process; the process is however only tested on a labscale.

The EAF furnaces at Nedstaal use approximately 1.6 GJ_e per tonne liquid steel (1993/1994, [77]). This is well in line with the data for the UHP furnace in Table 6.2, taking the scale effects into account (Nedstaal produces 200-250 kt steel per year with two EAF furnaces, so the furnace size is only a quarter of the furnaces in Table 6.2). Nedstaal uses approximately 3.3 GJ fossil fuels and 2.2 GJ electricity, if the total energy consumption is divided by the amount of cast product. Table 6.3 shows the energy consumption per process operation.

Energy consumption figures for scrap smelters should be compared with care, because the total energy consumption depends highly on the plant size and the product mix. For example, the energy consumption for wire drawing depends largely on the final thickness of the wire (Figure 6.3).

Nedstaal is a small, specialised EAF steel producer for speciality steels. As a consequence, a comparison with large-scale EAF steel plants for bulk steel production makes little sense.

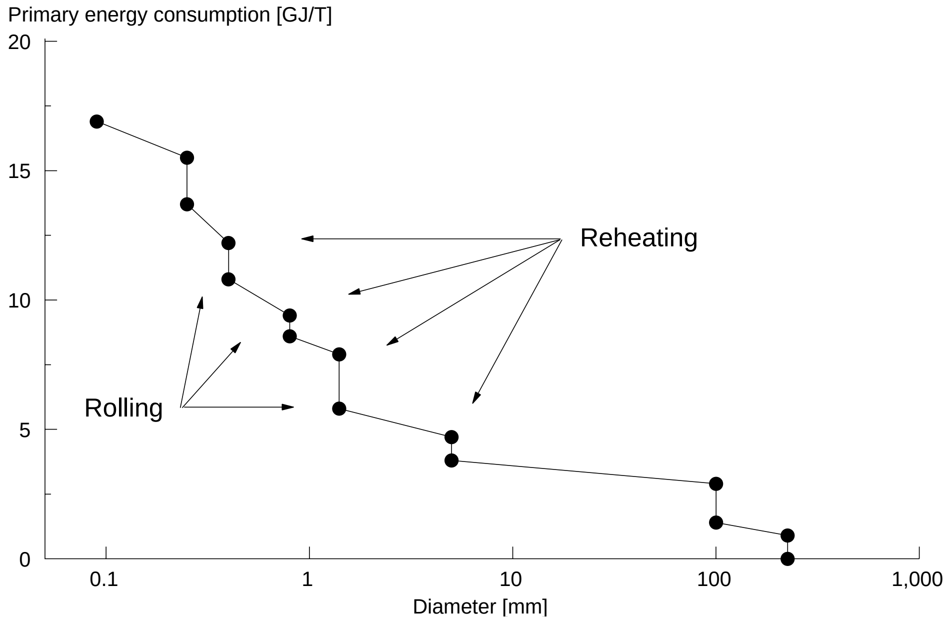

Figure 6.3 *Energy consumption for conventional rolling and drawing from ingot to wire (Stainless steel 2333) [82]*

Table 6.2 *Final energy balance for different types of scrap smelting furnaces [81]*

Input	[GJ/t]	Output	[GJ/t]
Conventional EAF + scrap preheat 500 kt/year			
Electricity	1.54	Hot metal	1.37
Scrap oxydation	0.79	Hot slag	0.17
Gas	0.05	Cooling water	0.31
Scrap preheat	0.12	Waste gases	0.47
Electrodes/slag formation	0.13	Losses	0.32
Total	2.63		2.63
Contiarc 500 kt/year			
Electricity	0.93	Hot metal	1.37
Scrap oxydation	0.79	Hot slag	0.17
Gas	0.05	Cooling water	0.11
Scrap preheat	0.12	Waste gases	0.17
Electrodes/slag formation	0.07	Losses	0.14
Total	1.96		1.96

Table 6.3 *Energy use per process step, 1993/1994 [77]*

Process	Production [kt pa]	Electricity [GJ_e/t]	Fossil fuel [GJ/t]	Primary [GJ/t]
EAF furnaces+casting	209	1.72	0.47	4.76
Reheat+bloom production	209	0.22	1.07	1.61
Bloom treatment	147	0.06	-	0.15
Rolling	234	0.38-0.60	1.24-1.38	2.33-2.79
Pickling	111	0.03-0.05	0.13-0.30	0.43-0.46
Drawing	38	0.16	-	0.40
Annealing	68	0.18	1.40	1.84

Nedstaal is able to produce high qualities of steel because of its batch process. The company uses a mixture of process scrap and post-consumer scrap and applies a strict scrap selection in order to control the steel quality. Because of the vertical ingot casting, high and low density contaminants can be cut from the ingot bottom and top part, respectively. These ingot parts can again be recycled. Nedstaal claims that most steel purities can be delivered in this way. This quality improvement is however only feasible at the expense of its higher energy input.

Electric arc furnaces produce primarily reinforcement bars and steel bars because the scrap quality limits the product quality. Very low carbon steels containing less than 0.04% C cannot be produced economically in EAF furnaces because they require significantly enhanced oxygen injection, causing high FeO slag and excessive yield loss. EAF producers are however slowly moving into the sheet market for e.g. household equipment. Secondary metallurgal processes like ladle furnaces (LF) and vacuum oxygen degassing (VOD) are nowadays widely used in order to enhance the product quality and to provide a broader scope of steel qualities [83].

The scrap availability is still essential for major expansion of EAF capacity on a European scale, not the product quality. Direct Reduced Iron (DRI) can however substitute for scrap. If future scrap quality problems occur, the addition of DRI can solve such problems. DRI is however more expensive than steel scrap, so the advantage of EAF producers will decrease (see Chapter 11).

Steel scrap quality is an important factor in the recycling, because it determines to some extent the quality of the secondary steel. DRI and Iron produced from iron ore contain significantly lower amounts of trace elements and unspecified residual elements. An overview of these elements and the minimum requirements for certain applications is shown in Table 6.4.

Table 6.4 *Typical tramp elements and unspecified residual element limits in selected carbon steels and scrap qualities [84]*

Steel grade	Total Cu+Sn+Ni+Cr+Mo [%]
Maximum content	
Tinplate for draw and iron cans	0.12
Extra deep drawing quality steel	0.14
Drawing quality and enamelling steels	0.16
Commercial quality sheet	0.22
Fine wire grades	0.25
Special bar quality	0.35
Merchant bar quality	0.50
Characteristic content	
DRI	0.02
Pig iron	0.06
(American scrap standards)	
Scrap: no. 1 factory bundles	0.13
Scrap: bushelling	0.20
Scrap: shredded cars	0.51
Scrap: no. 2 heavy melting (mixed scrap)	0.73

Table 6.4 shows that especially car scrap and no. 2 heavy melting scrap cannot be used for all mentioned steel qualities. This should however pose no problems in the next two decades, as scrap exports and production of reinforcement bars can serve as sinks for secondary steel of lower qualities. Current practice is to mix some scrap into the primary steel production. This process results in a dilution of trace elements and a gradual increase of these elements in the whole steel product stock. It may be currently a cost-effective solution for steel companies, it remains to see if this strategy pays off on the long term. In the same time period the trace elements build up in the steel stock, the steel quality requirements increase because of increased steel purity requirements, e.g. for transportation applications. On the longer run, dilution can pose serious problems for high quality recycling, new upgrading processes may be necessary.

With regard to galvanised steel scrap (zinc coated steel sheet), this scrap quality can be recycled in electric arc furnaces while recycling in basic oxygen furnaces is only possible after costly zinc removal. The zinc is recovered in the filter dust of the EAF which can be recycled in the zinc industry. Because the fraction of zinc coated steel is rapidly increasing, this is an important advantage for EAF steel producers.

Another important problem regarding scrap recycling is copper contamination. Copper originates from electric motors and from copper wiring. Especially for shredder waste, copper poses a problem. Shredder waste contains currently 0.8% copper. This results in 1.25% copper in the liquid steel if this scrap is processed in EAF furnaces. This high content limits the application of this scrap type. A maximum dismantling scheme can reduce the copper content to 0.5% in the liquid steel. Mechanic processing through shredding and subsequent magnetic separation reduces the copper content to that of standard scrap grades [85]. Dismantling schemes are currently planned in the Netherlands. These schemes will significantly increase the range of applications for steel scrap from shredders.

Scrap can be upgraded by separation and treatment systems. Balers, shears and shredders are used to upgrade waste products to steel scrap that can serve as input for EAF or BOF steelmaking. Operating costs are 60, 50 and 90 NLG, respectively. A description of these technologies can be found in [86]. For some scrap types, detinning is used to generate a more suitable scrap quality. Scrap collection in the Netherlands is organised like a pyramid. At the bottom are 1500 small traders who generally sell to roughly 100 regional traders and these roughly to five exporters. Steel scrap is generally sold according to the US steel scrap qualifications.

7. STEEL COSTS AND REVENUES

7.1 General cost structure

A first general cost structure analysis is provided in Figure 7.1. Energy and feedstock costs are important at the beginning of the steel chain, but rapidly decrease in importance for semi-finished and finished steel products. In the finished products, they make up 3% of the total costs. The significance of the product specifications is further elaborated in Table 7.1. Crude steel costs approximately 370 NLG per tonne. Semi-finished products cost 2-6 times as much, depending on the product characteristics. The price for finished steel products is 5-40 times as high as for crude steel. Table 7.1 shows also that stainless steel (alloys) have a price that is significantly higher than for plain steel. The price advantage decreases however moving along the steel chain. For finished steel products, the price advantage is relatively small.

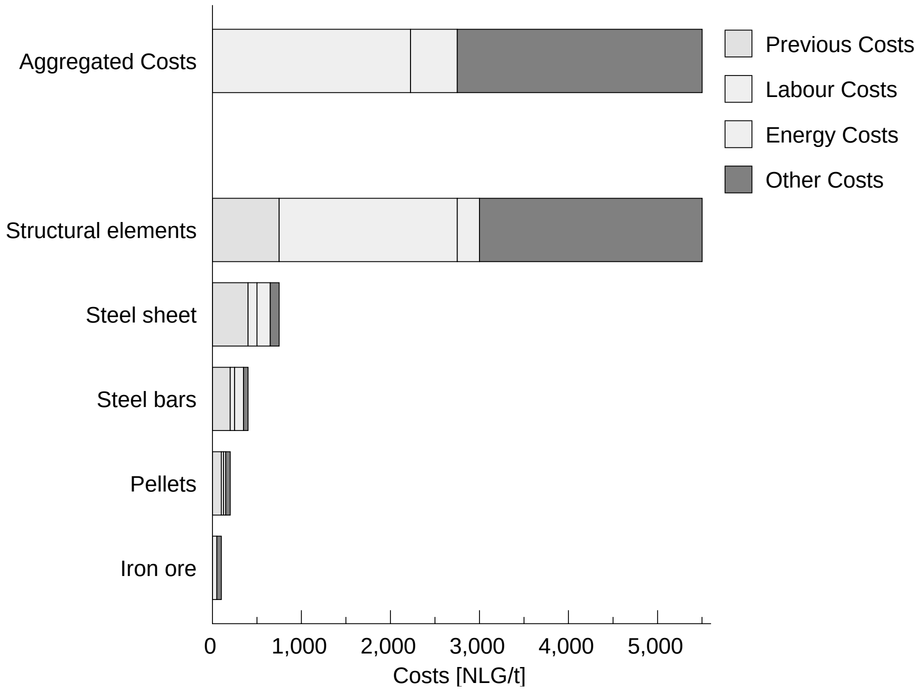

Figure 7.1 *Cost structure in the steel chain*

Table 7.1 *Dutch export prices of different steel products, 1993*

SITC code	Product	Price [NLG/t]
Iron/steel		
720110190	Cast iron	296
720712100	Steel slabs, <0.25% carbon	367
720241900	Ferrochrome, >6% carbon	1135
721810000	Stainless steel	8166
Semi-finished products		
720822980	Steel coils, 4.75<d<10 mm	550
720824100	Steel coil, d<3 mm	620
720844900	Steel sheet 3<d<4.75 mm	644
720922900	Steel coil 1<d<3 mm	794
720923900	Steel coil 0.5<d<1 mm	739
721012110	Steel sheet d<0.5 mm, coated	1513
721049100	Steel sheet, surface treated	845
721210100	Tin plate	1274
721331000	Wire, <0.25% carbon, diameter<14 mm	627
721420000	Concrete reinforcement bars	515
721631110	U-profiles, 80<h<220	687
721632110	I-profiles, 80<h<220	702
721633100	H-profiles, 80<h<180	694
721921110	Stainless steel sheets, d>13 mm, >2.5% Ni	4091
721933100	Stainless steel sheets, 1<d<3 mm, >2.5% Ni	3406
730110000	Sheet piles	1481
730431910	Steel tubes, seamless	2357
730410100	Steel tubes, seamless, d>168.3 mm	2197
730449910	Stainless steel tubes, seamless, d<406.4 mm	13556
Finished products		
730830000	Doors and frames	10679
730890990	Structural elements	5588
730900300	Reservoirs, including insulation	17262
732393900	Kitchen ware	7645

Figures 7.2 and 7.3 show the long-term and short-term steel price trends. Steel prices decreased significantly in real terms. The price decrease is even more significant in Dutch guilders than in US$. Prices decreased by 50-70% in the period 1960 to 1990. Compared to aluminium (Figure 5.2), the graph shows significantly less marked variations in prices. The short-term developments in Figure 7.3 show also relatively stable prices over the period 1989-1993.

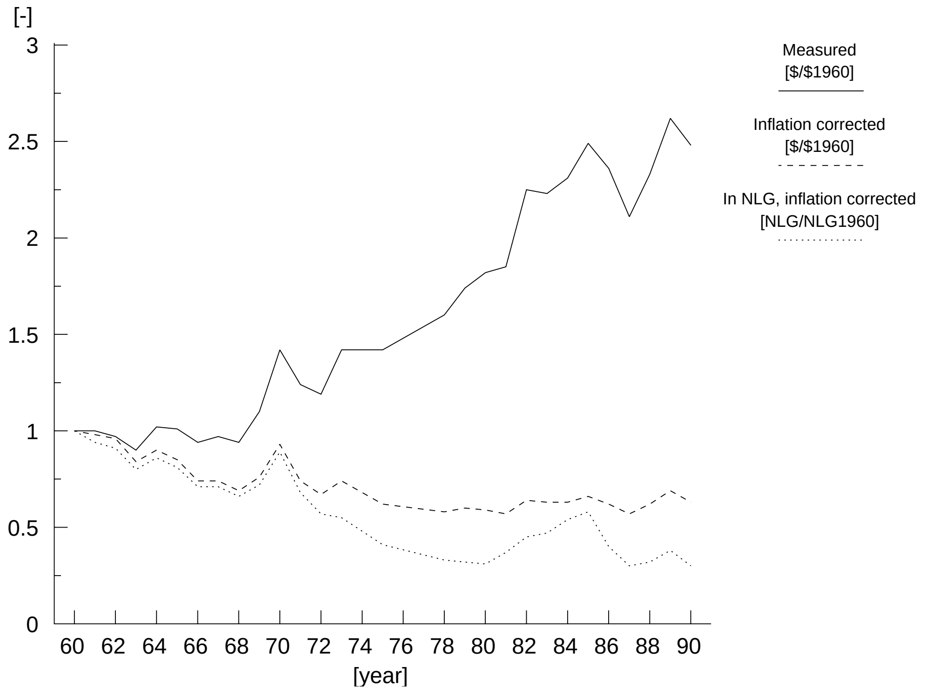

Figure 7.2 *Steel price trends 1960-1990 (1960=1)*

Figure 7.3 *Short term price changes in the steel chain, period 1989-1993*

7.2 Capital costs

The steel industry is capital intensive. Because of the large size of single steel plants, investment costs of one single plant are billions of guilders. Capital costs can be divided into different processes. Investment costs are listed in Table 7.2.

Table 7.2 *Investment costs per steel process [87]*

Process	Investment [NLG/t output]	Capital costs [NLG/t output]	Use [t/t sheet]	Capital costs [NLG/t sheet]
Coke oven	600	66	0.33	22
Sinter plant	50	6	0.71	4
Pellet plant	150	16	0.71	11
Blast furnace	150	16	0.95	15
BOF	200	22	1.00	22
EAF furnace	100	11	1.00	11
Continuous casting	100	11	1.00	11
Hot rolling mill	150	16	1.00	16
Cold rolling mill	150	16	1.00	16
Total for blast furnace route				*117*
Total for EAF route				*54*

Assuming an interest rate of 5% and 3% inflation, a depreciation in 25 years and a utilisation rate of 85%, the capital costs can be calculated. These costs are shown in Table 7.2.

Based on these figures, the capital costs for Hoogovens can be estimated. Assuming that 1/3 of the total production is sold as slabs, 2/3 production is hot rolled and 1/3 is hot and cold rolled, total capital costs amount to 600 million guilders.

7.3 Independent costs

7.3.1 Labour Costs

Hoogovens Staal employs approximately 10,500 people and produces 6.0 Mt steel (1996 figures). The labour productivity increased significantly in recent years due to large-scale reorganisations. For example in 1993, 12,000 employees produced 5.6 Mt steel: the increase in labour productivity is 18% in a period of 3 years. The average costs per employee for Hoogovens are 90,000 guilders (approx. 50 guilders per hour). As a consequence, the average labour costs per tonne steel product are 160 guilders. The bottom-up calculation should generate similar figures.

Table 7.3 *Labour costs per steel process [87]*

Process	Labour requirements [hours/t output]	Labour costs [NLG/t output]	Use [t/t]	Labour costs [t/t sheet]
Coke oven	0.45	22.5	0.33	7
Sinter plant	0.28	14.0	0.71	10
Pellet plant	0.21	10.5	0.71	7
Blast furnace	0.40	20.0	0.95	19
BOF	0.64	32.0	1.00	32
EAF furnace	0.64	32.0	1.00	32
Continuous casting	0.35	17.5	1.00	18
Hot rolling mill	0.30	15.0	1.00	15
Cold rolling mill	0.25	12.5	1.00	13
Total for blast furnace route				*121*
Total for EAF route				*78*

The total in Table 7.3 is only 121 guilders labour costs. Table 7.3 does however not include staff units like sales departments, research facilities, engineering facilities, management. The labour costs that are not accounted for an integrated steel plant are approximately 50% higher.

7.3.2 Other independent costs

Other independent costs occur because of maintenance, insurance, depreciation of working capital. These annual costs are assumed to be 5% of the total investment costs. It is assumed that this fraction is the same for all processes.

7.4 Utilization costs

Utilization costs can be divided into energy costs and materials costs. Both will be discussed together, as the division is generally artificial. The energy and material inputs and outputs of processes are discussed in Appendix B. With regard to transportation costs, the analysis in section 5.4.5 for aluminium provides detailed information. In this section, the transportation costs for German steel mills and Hoogovens are compared for different markets in order to show the impact of location on competitiveness.

Energy and raw materials

The most significant variable costs are coke and coal costs and iron ore costs. Cost trends for both resources are shown in Figure 7.4 and 7.5.

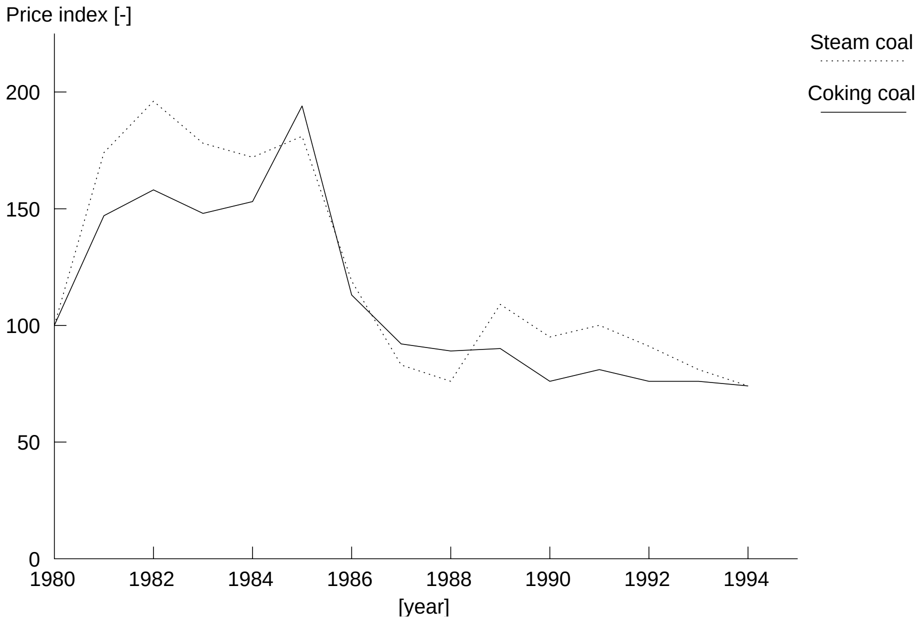

Figure 7.4 *Steam coal and coking coal prices, 1980-1994, CIF Rotterdam (1980=100) [88]*

The price trends for steam coal and coking coal in Figure 7.5 are similar: both show a steep rise in the beginning of the 80's and a decline in the 90's. Part of this development is accounted for by exchange rate fluctuations: coal prices are quoted in US$. Figure 7.5 indicates no trend differences between steam coal and coking coal in the last 15 years.

Prices for coking coal and steam coal imports into the EEC are analysed in Table 7.4. The price comparison per tonne may be misleading because the heating value of coal types ranges from 25 to 30 GJ/t. The heating value of coking coal is higher than for steamcoal. In Table 7.4, the prices are recalculated into costs per GJ, assuming an energy content of 26 GJ/t for steam coal and 29 GJ/t for coking coal. Coking coal prices are per unit of energy 10% higher than steamcoal prices. This difference is relevant in Chapter 11 and 12, where iron technologies are compared that use either coking coal or steamcoal.

Table 7.4 *Coal import prices (CIF, 1992 average) [89]*

Source	Coking coal		Steam coal	
	[NLG/t]	[NLG/GJ]	[NLG/t]	[NLG/GJ]
Australia	107	3.7	86	3.3
USA	108	3.7	87	3.3
South Africa	89	3.1	75	2.9
Poland	105	3.7	94	3.6

The energy consumption for the ferrous basic metal industry in 1994 (excluding the coke ovens) is shown in Table 2.3. Coal, natural gas and electricity are the main inputs. Assuming a coal price of 3 guilders per GJ, a natural gas price of 6 guilders per GJ and an electricity price of 20 guilders per GJ, Hoogovens' energy costs are estimated to be 400 million guilders. One should emphasize that this definition of energy costs includes coal and coke that are used as feedstocks. These fossil fuels are normally not included in the energy costs in the Hoogovens' statistics.

The price trend for iron ore is shown in Figure 7.5. The prices are expressed per 1% iron content for dry ore. The iron content of ores ranges from 57 to 66%, the remainder being oxygen, SiO_2 (1-6%), Al_2O_3 (0.5-3%) and moisture (2-9%). The data in Figure 7.5 refer to FOB prices for delivery in Northern German ports. Only the Hamersley price is a CIF price (including transportation). Ore transportation prices are determined by the dominant market party. The CIF import price for Rotterdam of Brazilian ore fines is the price that determines the prices of the other iron ore types. This can be seen in Figure 7.5, where all ore types show the same price trend. In actual monetary units, ore prices remained almost stable. In real terms, ore prices decreased significantly in the last 20 years (see Figure 7.6). This decrease can be attributed to increased competition and decreasing production costs due to technological progress.

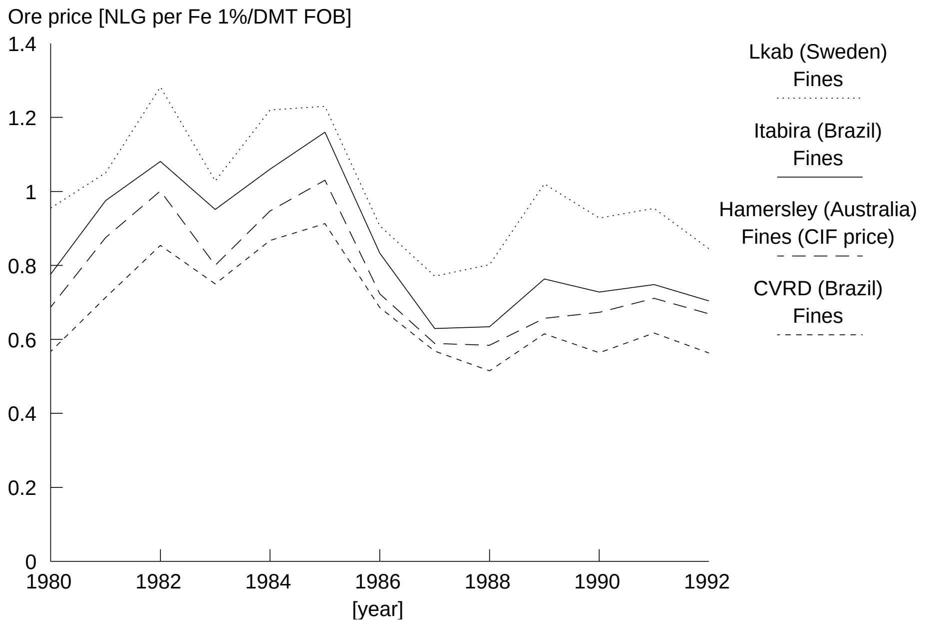

Figure 7.5 *Iron ore price trend in NLG per % iron in the ore (dry matter), excluding transportation (Hamersley ore including transportation) [90]*

Figure 7.6 *Real and actual ore prices, Brazilian Itabira standard sinter fines, CIF German ports. Real price expressed in terms of 1992 constant prices, adjusted by US GDP deflator*

Scrap prices for different scrap qualities are shown in Table 7.5. These prices refer to qualities according to the UK standards. Note the price differences: a factor two between the cheapest and the most expensive scrap type. These differences can be attributed to the difficulties in handling and to the level of contamination. The application of contaminated scrap is limited to steel with low quality requirements, eg reinforcement bars (see Table 6.1). Scrap prices can heavily fluctuate in a relatively short period: a difference of a factor two within one year is not uncommon. The scrap market is a global market with many suppliers and consumers. These price fluctuations can be attributed to the short-term fluctuations in global scrap demand.

Comparison of steel and aluminium scrap prices in Table 5.4 and Table 7.5 shows that the relative price difference is of the same order of magnitude. The absolute price difference is for aluminium however five times as high. As a consequence, assessment of the profitability of aluminium recycling is more sensitive with regard to scrap price fluctuations.

Table 7.5 *Steel scrap price for different scrap qualities (UK, January 1995, including delivery) [91]*

Scrap type	Scrap price [NLG/t]
Old heavy steel	208
No 1 Old steel	193
3B fragmentised (shredded)	224
4A New steel bales	249
7A Heavy steel turnings	146
8A New loose light cuttings	148
9A Heavy cast iron	161
9B Cylinder block scrap	300
10 Light cast iron	155
12A New production steel	202

Hoogovens bought in 1993 approximately 8 Mt iron ore, the (CIF) value is 480 million guilders. The costs for 0.6 Mt scrap were approximately 120 million guiders, the total costs of the raw materials were 600 million guilders.

Transportation costs

Transportation costs for steel mills depend on the location relative to the resources and relative to the consumer. The transportation costs for Hoogovens and for German steel mills in the Ruhr area are compared for two markets: exports to foreign continents and production for the German market.

In case of production for foreign markets, the German producers must (relative to Hoogovens) additionally pay for transportation of ore and coal from Rotterdam or Antwerp to their production site. The products are shipped back to the harbour. In case of production for the German market, the German producers must additionally pay for transportation of ore and coal to their production site. They save however approximately half to three quarters of the transportation costs for the products. Table 7.6 shows the analysis of the additional costs for the German producers.

Table 7.6 *Additional transportation costs for German producers (Western Ruhr area), compared to Hoogovens [92]*

Type	Amount [t/t]	Additional costs [NLG/t]	Total
Production for export markets			
Ore	1.5	7.5	11.3
Coal	0.7	7.5	5.3
Product	1.0	20.0	20.0
Total			36.6
Production for the German market			
Ore	1.5	7.5	11.3
Coal	0.7	7.5	5.3
Product	1.0	-15.0	-15.0
Total			1.6

Table 7.6 shows clearly the disadvantage of an inland location for production for exports. The disadvantage of 30 guilders represents up to 10% of the total production costs, depending on the product (see Table 7.1). It is remarkable that transportation costs are even slightly higher for the German market. This result depends however on the relative transportation costs of raw materials and products. The transportation costs for products vary per product type.

The total transportation costs for Hoogovens were approximately 600 million guilders. This sum includes the transportation costs for raw materials. The transportation costs for the steel products are an estimated 300 million guilders.

7.5 Revenues

Revenues for the Dutch steel industry are shown in Table 7.7. Data are based on production statistics and price data in Table 7.1.

Table 7.7 *Revenues for the Dutch steel industry, 1993 [93]*

	Amount [t/year]	Price [NLG/t]	Revenue [MNLG/year]
Hot rolled coils	1126	550	619
Hot rolled sheet	81	550	45
Hot rolled strips	153	550	84
Cold rolled coils	1706	800	938
Cold rolled sheet, galvanised	523	1275	667
Wire	218	625	136
Concrete reinforcement steel	363	520	189
Slabs and semi-finished products	1781	375	668
Tinplate	pm	pm	pm
Total			3346

7.6 Summary of the cost and revenues in the Netherlands

Costs and revenues in the steel industry are shown in Figure 7.7. Both cost structures refer to the total industrial complex of Hoogovens and Nedstaal, respectively. The data show that even for the energy intensive steel industry, energy costs constitute only a small part of the total production costs. Labour costs are still the main fraction, followed by raw materials. Together, they constitute more than half of the total production costs.

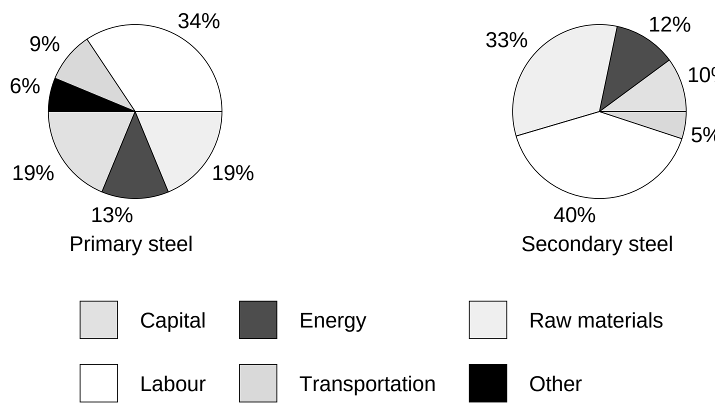

Figure 7.7 *Cost structure in the Dutch primary and secondary steel industry, 1993*

Table 7.8 *Costs and Revenues in the Dutch steel industry, 1993*

Costs	Hoogovens [10^6 NLG pa]	Nedstaal [10^6 NLG pa]
Energy	400	23
Raw materials	600	65
Labour	1100	80
Capital	600	20 (est.)
Other	500	10 (est.)
Total Costs	3200	198
Total Revenues	3186	160
Net Profits	-16	-38

Table 7.8 shows small losses for Hoogovens and indicates more significant losses for Nedstaal. The latter one is however rather uncertain because of the uncertainties with regard to the average product price. Because the definitions in this chapter differ from the definitions in the annual financial reports of the companies, a straightforward comparison is not possible. The capital costs are generally based on new investments instead of being based on the depreciation, like in this study. The annual reports show however that 1993 was a particularly bad year for the steel industry. The steel industry is a cyclic industry; the profitability has increased significantly in recent years.

8. GENERAL OTHER FACTORS

Additional to the aspects which were quantified in Chapter 5 and Chapter 7, several factors that are difficult to quantify may be important in the choice of production locations and the possibility to compete with other countries. The aspects discussed in this chapter are limited to those that are beforehand thought to be most relevant: industrial policy, environmental rules and policies and human capital. A summary is based on a recent publication of the Ministry of Economic Affairs, 'Toets op het concurrentievermogen' [94] (test for the capacity to compete).

8.1 Industry policy

Subsidy control

The European Union is trying to achieve an open market within the union by prohibiting national governments to provide subsidies that disturb competition. All subsidies are forbidden unless approved by the commission. A set of rules is issued by the commission that allows structural subsidies for industries that are considered of vital importance for the economies such as the Dutch basic metal industry.

Massive governmental subsidies to support the own steel industry are nowadays limited. With regard to the steel industry, the subsidies are subject to a set of strict rules issued by the European Community for Coal and Steel (ECCS). Government participation is rapidly decreasing. Subsidies for basic R&D are allowed up to a level of 25%. Subsidies for environmental R&D are allowed up to a level of 30%.

Research and development

Little of the process know-how used in the Dutch aluminium industry is developed in the Netherlands. The main reason is that the technology is mature; general aluminium production process know-how is traded freely. Most of the technology know-how that is used in the Netherlands has been developed abroad. The main research is currently going on at the technological universities and focuses on aluminium finishing: e.g. RSP aluminium (see Chapter 10), finishing and bonding technologies, Eddy Current separation technology.

Concerning steel, Hoogovens has substantial research into new steel production technologies, improved products and new steel finishing technologies. The company spent in 1995 110 million guilders on R&D (both for steel and aluminium) [95]. The research focuses on the applications, especially the transportation sector. Most research is performed in-house; approximately 10% is realised in cooperation with government research establishments, universities and private non-profit organisations. Research institutes like ECN and TNO and the universities in Twente, Delft and Eindhoven offer research facilities.

Nedstaal is a much smaller company with limited research facilities. Current research regarding production technologies focuses on the introduction of new, larger EAF furnaces and continuous casting. The company is focusing its research on specialty products that cannot be made by any other European steel producer, like special types of steel springs for the automobile industry.

The recent announcement of a top research institute for metals can further enhance the R&D efforts. Twenty years ago the Dutch industry was listed second after the USA in R&D expenditures. Nowadays almost all important industrial countries invest relatively more in know-how than the Netherlands. The Dutch government diminished her R&D subsidies to a share of 7.5% of the total industrial investment for innovation. Meanwhile other governments enlarged their contribution for R&D to a share up to 30%. Nowadays the Dutch government tries to fill this gap by offering 12,5% tax-deduction of the R&D labour costs with a maximum of 10 million guilders per firm [96,97].

Investment subsidies

Recently a new investment aid has been developed in the Netherlands. This so called industry facility is meant for capital intensive industries that face financing problems for innovations. If financial institutions find the risks of investing too high, industries can borrow from a fund raised by an assembly of governmental and private institutions. The industry facility can contribute to a maximum of 900 million guilders.

Product standards

The European Union plays an important role by setting technical standards and security standards for products. Before these European product standards and regulations were issued, countries could use national regulations to reduce competition from other countries. The steel and aluminium products are nowadays largely standardised.

Investment climate

Investment decisions are only to a limited extent based on the expected profitability. Political stability, an efficient bureaucracy, good infrastructure, cultural compatibility are among the less quantitative aspects that are considered in the investment decision making process. Western economies are generally much higher rated with regard to these aspects than developing countries. The multi-criteria analysis that is required for proper assessment extends beyond the scope of this analysis, but the consequences for investment decisions should be kept in mind. This caveat will become especially apparent for primary aluminium production, see Chapter 11.

8.2 Environmental rules and regulations

In the Netherlands, concern about the environment has deepened in recent years. This concern has resulted in a number of policy documents and plans. The impact of environmental rules and regulations is becoming more and more important in the basic metal industry. The average environmental costs for the basic metal industry amounted in 1992 7.4% of the added value. Hoogovens reported for 1994 environmental costs of 34 guilders per tonne steel. These costs represent 10% of the total production costs for steel slabs. Aluminium Hardenberg reported for 1994 environmental costs of 90 guilders per tonne aluminium [98]. These costs represent 3.2% of the total production costs. The cost difference between both companies indicates the different environmental impact.

Table 8.1 *Environmental net costs in the Dutch basic metal industry 1992 [99]*

	[%]
Own environmental activities	82
Received subsidies	7
Environmental levies and expenses	11
Total net environmental costs	100

Several environmental regulations have stimulated industries to invest in cleaner technologies.

Business Plan for Energy efficiency and the Environment

A declaration of intentions concerning the implementation of environmental policies was signed between the basic metal industry and the government in 1992 [100]. The declaration covers all environmental policy areas and contains the intended environmental improvements for the period 1992-2010. The main issues concerning the steel industry and the aluminium industry are airborne emissions and energy efficiency (see Section 2.5 and Chapter 10 regarding energy efficiency).

Airborne emissions

Emissions from primary aluminium production are summarised in Table 8.2. The table shows that a significant part of the national fluorine emissions and fluorocarbon emissions arise from primary aluminium production. Direct CO_2 emissions are relatively low. This does however not include the CO_2 emissions related to the electricity consumption (approx. 2 Mt CO_2, if an average emission of 150 kg CO_2/GJ_e is assumed). Concerning the direct CO_2 emissions, the perfluorinated carbon (PFC) compounds (carbon compounds that are fully fluorinated) represent a much more important greenhouse gas emission than the anode conversion. The listed PFC emission depend highly on the frequency of anode effects, caused by low alumina content of the smelting bath when the cell voltage increases due to the bath resistance and perfluorinated carbon compounds can be generated [101]. The alumina content control depends on the alumina feeding system. Application of alumina point-feeders allows improved control of the alumina concentration and results in a reduction of PFC emissions by one order of magnitude. Point feeders could also be applied in the Netherlands, but imply investments in new feeding systems.

Table 8.2 *Direct emissions from Dutch primary aluminium production, 1992 [102,103]*

Type	Amount [kt/year]	National emission fraction [%]
NO_x	na	na
SO_2	1.0	0.8
Fluorine	0.135	10
CF_4+C_2F_6 (CO_2 equiv.)	2000	1
CO_2	400	0.2
CO	30	3

Concerning steel production, SO_2, CO_2, dioxins and CO emissions constitute a significant part of the total national emissions. CO_2 is not directly released, but arises if the CO/CO_2 mixture in the residual gases is combusted. These emissions are in Table 8.3 completely allocated to Hoogovens. The other emissions are closely related to certain processing steps. The emissions of SO_2, dioxins and CO have been further reduced since 1994 by introduction of a new sintering process, called EOS (Emission Optimized Sintering) [104].

Table 8.3 *Emissions from Hoogovens, 1994 [104,105]*

Type	Amount [kt/year]	National emission fraction [%]
NO_x	7.8	1.5
SO_2	8.0	5.4
CO_2	9000	5.6
CO	112	12.5
Dioxins [grammes]	20	20.6

Aluminum and steel industry waste

Apart from airborne emissions, waste management is another important environmental consequence of the production processes for both metals. Table 8.4 lists the waste release per tonne material.

Table 8.4 *Waste release [58,106]*

	[t/t metal]	Application
Primary aluminium		
Red mud	3.2	-
Fly ash	0.3	Cement (partially)
Other	0.1	-
Total	3.6	
Secondary aluminium		
Fly ash etc.	0.05	Cement (partially)
Dross residue	0.4	Cement/bricks
Total	0.1	
Primary steel		
Steel slag	0.08	Roads/waterworks
Other	0.04	-
Total	0.12	
Secondary steel		
Steel slag	0.1	
Fly ash etc.	0.1	Cement (partially)
Total	0.2	

The data show that the amount of waste is the largest for primary aluminium production, especially the red mud is a problem because of the large volumes involved and the lack of suitable applications. Because alumina production is concentrated in countries with low population densities, red mud is not considered a key issue by policy makers. Concerning steel, the major part of the waste arising (blast furnace slag) can be reused and has even a positive commercial value. As a consequence, waste is currently no major environmental policy issue for both steel and aluminium.

8.3 Human capital

Labour circumstances

In the Civil code and the Labour Act minimum conditions for labour conditions are established. Labour costs in the Netherlands are relatively low, compared to for example Germany. This may pose a significant advantage in the next few years, if competition increases.

Education

The availability of a well educated labour force is essential for a high developed technological industry. According to a comparative study of the competitiveness of the Netherlands with other countries (Germany, Belgium, Denmark, US, Japan), the higher education in the Netherlands is considered to be good [94]. This is shown by a relatively high number of graduates with a vocational training, bachelor and masters degree and a relatively good level of education.

8.4 Conclusions

The steel industry is still considered of strategic importance in many countries. However, state intervention in Western Europe is rapidly decreasing due to the strict rules from Brussels. The market is gradually changing to allow more competition. This may not yet be the case in other regions. For aluminium, the strategic character of the industry is historically considered less important. Within the framework of this study it is assumed that the general other factors like government intervention are of decreasing importance in the choice of location.

Environmental costs constitute currently already an important part of the production costs in the Netherlands. These costs are however related to the substantial environmental impact of primary steel and aluminium production in a densely populated country. These higher costs are off-set by the benefits of a large and well educated labour pool and benevolent industrial policies.

9. FOREIGN COMPETITORS

In order to find the most important foreign competitors for basic metal trade, the global resource availability, production capacity and supply structure is analysed on a continental aggregation level.

Historically, the basic metal industry in each of the key industrialised regions tended to be regionally specialized. The supply capability for basic metals matched the regional demand pattern. This pattern is however changing.

Especially the recent reduction of trade barriers (levies and quota) may significantly enhance international trade. Whether such a shift occurs will on the long term largely depend on production costs. Cost price structures abroad may differ from price structures in the Netherlands because of differences in:

1. raw material and energy prices
2. production technologies
3. investment costs
4. labour costs
5. legal constraints (e.g. environmental pollution abatement costs)
6. transportation costs.

Cost structures will be compared in Chapter 11 and Chapter 12.

9.1 Aluminium

World production can be split into several areas, defined by the raw materials supply situation and distance to product markets. Western Europe, North America, Russia and Australia make up the bulk of the existing production capacity.

It should be noted that competition in aluminium production takes place in an international arena where companies are the main players and not countries. Companies choose their production locations where conditions are favourable to them. For example the availability of high skilled labour, the proximity to a consumer market, a high developed infrastructure, low energy and feedstock prices are favourable conditions. The choice for a location can also be made by strategic considerations, like reduction of risks or getting foothold in promising regional markets. Maintaining or even starting production under cost conditions that are not optimal can be a rational decision from the company’s point of view. These strategic considerations may reduce the mobility of production capacity and therefore moderate competition between regions.

The discussion of the production and trade in bauxite, alumina and aluminium will follow the production route. Trends in the bauxite availability and bauxite production are discussed, followed by alumina production.

Finally, trade flows and production of primary and secondary aluminium are reviewed.

Bauxite

The raw material for aluminium production, bauxite, is found throughout the world, but a limited number of areas with large deposits dominate the global resource base. Table 9.1 shows bauxite resources by region. Two countries own nearly half of the total economically recoverable bauxite reserve (Guyana 25% and Australia 20%). Based on the current annual global primary aluminium production, bauxite reserves are certain for the next 200 years. As a consequence, no bauxite supply problems are expected for the next decades.

Table 9.1 *World bauxite resources by region, 1989 [107]*

Region	Reserves [Mtonnes]	Shares [%]
Africa	6870	32
Latin America	6440	30
Oceania	4400	20
Asia	1810	8
Western Europe	990	5
North America	40	0
Others	1000	5
Total world	21550	100

The largest *producer* of bauxite is Australia that increased its market share from non-existent in 1960 to 36% in 1993. Important other producers are Guinea (15%) and Jamaica (10%). The bauxite production is gradually shifting from Western and Eastern European countries to Australia, Africa and Latin America, locations with major bauxite reserves of superior quality. In the search for cost reduction certain types of ores have proved to be more efficient and this has increased the demand for Australian, Guinean and Brazilian bauxite. Intra-company trade remains predominant as far as bauxite is concerned: companies that own bauxite refiners are also involved in bauxite mining. The trade is usually arranged under long-term contracts. Due to high freight costs and energy prices bauxite refineries (alumina plants) are increasingly located near the mines.

Table 9.2 *World bauxite production by region, 1993 [108]*

Region	Production [Mt pa]	Share [%]
Oceania	41.1	36
Latin America	28.4	24
Africa	18.6	16
Eastern Europe + CIS	15.5	13
Asia	7.3	6
Western Europe	4.2	4
North America	0.0	0
Total world	115.1	100

Alumina

The growth of alumina production has followed the growth of bauxite production. World production roughly doubled between 1970 and 1990. In the wake of increasing bauxite mine exploitation alumina production in Australia quintupled over the same period (Table 9.3). Striking is the non-emergence of alumina industry in Africa, where bauxite production rose to a 17% market share in 1990 while maintaining its 1970 alumina market share of below 2%. Alumina production is rising in countries like Brazil, Jamaica, Surinam, Venezuela and India, all countries with indigenous bauxite reserves. This further illustrates the trend towards placing refining capacity near the resources, cutting back on transport costs and adding more value to the exports.

Table 9.3 *World alumina production by region, 1993 [108]*

Region	Production [kt pa]	Share [%]
Oceania	12.6	29
Latin America	7.9	18
Eastern Europe + CIS	7.9	18
North America	6.5	15
Western Europe	5.6	13
Asia	2.3	5
Africa	0.6	2
Total world	43.4	100

The trade in alumina is largely controlled by a limited number of companies active on both the supply and the demand side. Six companies own roughly 60% of alumina capacity, i.e. Alcoa (26%), Alcan (11%), Kaiser (7%), Reynolds (7%), Pechiney (5%) and Alusuisse (4%).

Primary and secondary aluminium

Table 9.4 shows the primary production capacity for 1993, where Western Europe has the third position. Remarkable is the strong position of the Eastern European/CIS countries. This includes mainly Russian plants with little or no electricity costs due to the existing hydropower capacity that has been paid for in the former central planning system.

Table 9.4 *World primary aluminium capacity by region, 1993 [108]*

Region	Production [Mt pa]	Share [%]
North America	6.0	31
Eastern Europe + CIS	4.5	23
Western Europe	3.3	17
Latin America	1.9	10
Oceania	1.6	8
Asia	1.5	8
Africa	0.6	3
Total world	19.5	100

The 1970-1990 period showed a relocation of aluminium smelter production from sites close to consumer markets to the sites with low electricity costs. On average the aluminium production in the world grew at a rate of 2% per year over the 1970-1990 period. The smelting capacity in developing countries grew, while capacity in industrialised and former centrally planned economies stabilised. Asian capacity is expected to grow further mainly due to new capacity in India and Indonesia. Some Middle East countries plan new primary aluminium smelters (Saudi Arabia, Qatar). Latin America has seen rapid growth, enabled by the presence of alumina and cheap hydroelectricity.

The global secondary aluminium production is shown in Table 9.5. The world average share of secondary aluminium production in total aluminium production is roughly one quarter. Significantly lower fractions are encountered in Africa, Latin America and Australia, a much higher fraction in Asia, a figure dominated by Japan, that accounts for 85% of the Asian production. These differences are related to the regional availability of aluminium scrap. The position of Europe in secondary aluminium production is stronger than in primary production because of regional scrap availability and the less dominant energy price factor than in primary production.

Table 9.5 *World secondary aluminium production by region, 1990*

Region	Production [Mt pa]	Share [%]
North America	1.8	33
Western Europe	1.6	30
Asia	1.4	26
Africa	0.6	11
Eastern Europe + CIS	0.5	9
Latin America	0.0	0
Oceania	0.0	0
Total world	5.4	100

World trade in aluminium quadrupled between 1970 and 1990. This increase reflects the trend away from location of smelters near consumer markets. As energy prices are becoming more and more a determining production cost factor, the location of smelters near low cost energy sources and preferably also near alumina sources is preferred. Although Canada remains the most important aluminium exporter in weight units, its share of the global amount of aluminium supplied for export decreased from some 35% in 1970 to 14% in 1990. In contrast, Australia’s share rose in the same period from 2.3% to 10% due to a policy of low price coal based electricity production. Japan is by far the most important aluminium importer because is has closed down most of its primary aluminium smelting capacity as a result of a national policy to reduce the dependency of the economy on energy imports.

Table 9.6 *Global primary aluminium producers, 1994 [109,110]*

Company name	Headquarters	Production [kt pa]	Share [%]
Alcoa	USA	2067	14
Alcan	Canada	1435	9
Pechiney	France (1992)	956	6
Reynolds	USA	792	5
Alumax	USA	681	4
Norsk Hydro	Norway	618	4
Comalco	Australia	435	3
Kaiser	USA (1993)	396	3
VAW	Germany	390	3
Others		7430	49
amongst which:			
Hoogovens (1993)		*219*	
Total		15200	100

Table 9.6 shows that nine primary aluminium producers account for more than half of the total aluminium production. Comparison with the ownership of alumina plants shows almost the same list of companies. Note that the aluminium plant in Vlissingen, owned by Pechiney, is in the hands of the

third largest aluminium company, while Hoogovens is still a small aluminium producer with its 200 kt primary aluminium production capacity. The much larger number of recycling companies results in a better working market mechanism for aluminum alloys than for primary aluminium.

The analysis in this section showed that bauxite resources are concentrated in tropical countries. The production of alumina is increasingly relocated from North America and Europe to countries with ample bauxite resources. A similar trend can be discerned for primary aluminium production, where low labour costs and electricity prices are important criteria for relocation of capacity from the North American and European markets. The primary aluminium production is currently in a transition state, partially located close to the consumer markets and partially relocated to sites with low electricity costs. Aluminium recycling is concentrated in the countries where the scrap arises, with the main exception of Japan which imports significant amounts of aluminium scrap (driven by the demand for cast aluminium from the transportation industry and driven by the national aluminium policies).

In conclusion, the main competitors for primary aluminum production in coming years are expected in countries with low electricity costs. If bauxite is also available, this is an important advantage that can result in large production sites with control over the complete production chain. The small number of large companies possess sufficient capital for such major investment decisions. Sites with both low electricity prices and bauxite availability exist for example in Venezuela, Surinam, West-Africa and Indonesia. Also, competition from Russia or Iceland can be based on cheap electricity, which is still a considerable advantage compared to the Dutch primary aluminium producers. With the exception of Iceland, all countries in this list are however considered to be politically less stable than the Western economies. This may explain why the relocation is not (yet) complete. Increasing electricity demand in developing countries may also threaten future availability of cheap hydroelectricity.

9.2 Steel

Iron ore

The reserves of iron ore were estimated to be 72 billion tonnes in 1983. At that time the annual production of ore was such that the reserve to production ratio was 160 years. Asia, Australia, North and South America possess large iron ore deposits. Europe (not Western-Europe) is the continent with the largest reserves: almost 40% of world total reserves in 1983.

Since 1984 the production of iron ore showed some regional shifts. Western Europe has seen its production cut in half and also the production in the (former) centrally planned economies (especially the (former) USSR has dropped dramatically (99 Mton since 1984). Production grew in South America, Australia and Asia. The most significant growth occurred in Asia

(120 Mton in 10 years), mainly caused by increased Chinese production. Currently, the three major iron ore producers in the world are China, Brazil and the former USSR. These three countries accounted for 60% of world iron ore production in 1993.

Table 9.7 *World iron ore production by region, 1993*

Region	Production [Mt pa]	Share [%]
Asia	299.9	32
South America	183.4	20
Eastern Europe + CIS	154.6	17
Oceania	121.4	13
North America	99.0	10
Africa	44.8	5
Western Europe	33.6	3
Total world	936.7	100

Approximately 40% of total iron ore production is shipped to other continents. Latin America is the major exporting region (34% of total exports; 14% of world production); Australia is another main exporter. The European Union (52.1 Mton) and Japan (34.3 Mton) are the main clients.

Crude iron

Crude iron production is shown in Table 9.8. By far the largest production is situated in Asia. Western Europe has the second largest production.

Table 9.8 *World primary iron production by region (1993)*

Region	Production [Mt pa]	Share [%]
Asia	216.1	41
Western Europe	98.4	19
Eastern Europe + CIS	92.0	18
North America	64.9	12
South America	31.8	6
Africa	11.3	2
Oceania	8.1	2
Total world	528.7	100

The total trade volume of pig iron is small compared to the total primary iron production volume (<5%). The main exporters are the former Sovjet Union and Brazil, the Asian region accounts for most of the imports (>50% of the total world import).

The world steel production is analysed in Table 9.9. The table shows that the situation for steel is similar to the situation for pig iron. Asia is the most important producer, followed at a significant distance by Western Europe. The difference between steel production and pig iron production is accounted for by the use of scrap and DRI. Table 9.9 shows significant net steel exports for Western Europe, Eastern Europe and the CIS area, while Asia (especially China) and North America are important net importing regions.

Table 9.9 *World crude steel production by region (1993)*

Region	Production [Mt pa]	Net export [Mt pa]
Asia	275.5	-43.2
Western Europe	158.1	29.1
Eastern Europe + CIS	127.6	24.5
North America	113.0	-12.5
South America	33.7	8.7
Africa+Middle East	14.0	-8.4
Oceania	8.7	1.8
Total world	730.6	0.0

The international scrap trade is shown in Table 9.10. The situation is similar to the scrap situation for aluminium. The largest scrap consumption is concentrated in the most developed economies where most scrap arises: Western Europe and North America. Note that the Western European scrap market is fairly international with large imports and exports compared to its own consumption. This is however mainly internal Western European trade. The Western European net import in Table 9.10 includes Turkey (contrary to the net export of 5 Mt in Figure 3.5, where Turkey is excluded). In conclusion, the trade with countries outside the region is small.

Table 9.10 *Consumption, import and export of scrap by region (1993)*

	Consumption [Mt pa]	Net export [Mt pa]
Asia	96.3	-9.3
Western Europe	79.1	-2.6
North America	74.9	8.2
Eastern Europe + CIS	63.3	1.7
South America	12.8	-0.1
Oceania	1.0	0.8
Africa	na	na
Total world	327.4	

Table 9.10 shows that Asia is the most important scrap importer in the world. The main importers of the region are the Republic of South Korea, China and India, all countries that lack significant scrap resources.

Table 9.11 provides an overview of the major steel companies. Comparison of Table 9.11 and 9.6 shows some remarkable differences between the structure of the steel industry and the structure of the aluminium industry. A very limited number of aluminium producers possess the majority of the global primary aluminium capacity. The 10 largest steel producers own together only 19% of the steel production capacity, and they are followed by a very large number of other producers which are of the same order of magnitude. As a consequence, it seems the steel market approaches much more the ideal market than the aluminium market. Another important feature is however the national character of the steel companies. None are real multinationals, contrary to the major aluminium companies. The national steel companies produce primarily for regional markets. However, this feature may change. The fraction of steel products (sheet, tubes etc.) that is internationally traded increased by 40% between 1980 and 1992 to 139 Mt. The trade of steel in manufactured products (cars, consumer electronics) increased in the same period by 100% to 77 Mt. The intra-regional trade in 1993 was approximately 120 Mt, so 96 Mt was traded between the regions. This trade represents 13% of the total global steel production.

Table 9.11 *Major global steel companies [111]*

Producer	Country	Steel output [Mt pa]
Nippon steel	Japan	26.2
POSCO	South-Korea	22.1
Unisor Sacilor	France	18.5
British Steel	UK	12.9
Arbed	Luxembourg	11.9
USX	USA	11.5
Thyssen	Germany	10.7
Kawasaki	Japan	10.6
Sumitomo	Japan	10.4
Others		589.0
amongst which:		
Hoogovens		*6.2*
Total		723.8

9.3 Steel and aluminium trade summary

The aluminium industry trade flows can be explained by the different regions where the resources are available and where the demand arises. Bauxite is a tropical soil type. As a consequence, bauxite mining and alumina production is rapidly increasing in Australia, Latin America and Africa. The primary aluminium production is currently concentrated in the industrialised countries, where the aluminium consumption occurs. The primary aluminium production is however gradually shifting to countries with cheap electricity: Australia, Russia, Canada, Latin America and Norway. Western Europe became in the last decade an important net aluminum importing region. Aluminium recycling is concentrated in regions with ample supply of aluminium scrap, especially in the industrialised countries where the scrap arises.

A significant primary steel production is still an apparent characteristic of industrialised countries. As prime quality ore resources are concentrated in Brazil and Australia, this ore is shipped to Western Europe, Japan and the rest of Asia. Pig iron trade is negligible. Primary steel is in significant quantities exported from Western Europe and the Eastern Europe/CIS region to China and North America. Contrary to Western Europe and North America, the Asian steel market is currently characterized by rapid growth. However, the Asian production capacity grows simultaneously: the two largest steel companies in the world, Nippon Steel and POSCO, are Asian companies. These companies are 4 to 5 times the size of Hoogovens, the advantages of the economies of scale may be substantial.

The significant Western European net steel export is a remarkable difference compared to the situation for aluminium, because the supply situation for coking coal and especially iron ore is similarly bad as for bauxite and alumina.

The difference between the European steel and aluminium industries may be accounted for by the much higher significance of energy prices for primary aluminium production (see Figure 5.6 and 7.7), by historical choice of production locations in the steel industry, and by the high technological standards of European steel producers. The steel production is also vertically more integrated due to high transportation costs. This may also explain the current location at the historical production sites. Both for aluminium and for steel, the secondary metal industry seems to be based on regional scrap availability. For both scrap types, Europe is in a good position.

10. TECHNICAL IMPROVEMENT OPTIONS

10.1 Aluminium

The Hall-Héroult process in itself is considered a mature technology. Significant technological improvements are not expected for coming years. New process routes for aluminium production out of bauxite were tested in the last decades but were abandoned because of major technological problems. There is an autonomous efficiency improvement in the Hall Héroult process because of improved cell design, improved feeding systems, improved bath composition, new cathodes etc.. This autonomous trend results in a decline in the energy consumption for the best available technology in the range of 0.2 to 0.5% per year. Energy savings are actively pursued by aluminium producers because of the high fraction of electricity costs in the total production costs in most countries. Apart from the small improvements that are considered autonomous developments, more significant improvements may be achieved by introduction of inert anodes, new cathodes and development of drained aluminium cells. The goal is generally to reduce the overvoltage in the aluminium cells in order to increase the electric efficiency. New cathodes and anodes will be discussed in more detail further on in this section.

With regard to recycling, important improvements can be achieved by increased waste recovery and technologies for recycling of alloys. One such technology is the RSP technology (Rapidly Solidification Processing), that is developed by the technical university in Delft and a number of Dutch recycling companies. Liquid secondary aluminium is cast on a rapidly spinning wheel, where the material structure is frozen through very fast cooling. The result is aluminium alloy with very fine crystals that can be extruded and possesses new physical properties. This allows the use of contaminated scrap to produce aluminium alloys of similar quality as conventional wrought aluminium alloys. Scrap can at this moment only be recycled into cast alloys.

RSP technology can on the long run solve potential recycling problems [112,113,114]. However, the use of such technologies seems not yet necessary from a scrap recycling point of view in the next two decades. Aluminium scrap can be shipped around the world without major cost increase, and aluminum demand will keep rising steeply around the world. RSA may however become attractive because it results in alloys with new properties. This option will not be discussed in more detail.

New cathodes

Currently liquid aluminium is used as cell cathode material. The molten aluminium fluctuates in height due to waves formed by electromagnetic and hydrodynamic effects. This unstable surface of the cathode can cause short-circuiting of the cell. To avoid this effect, conventional cells separate the anode and cathode by a large gap, resulting in high voltage differences and low average energy efficiencies for the cells of less than 50%.

In contrast, titanium diboride cathodes can be wetted with a thin film of aluminium, which then drains to a sump. This provides a stable cathodic surface, allowing the cell to operate with a much narrower anode-cathode gap. The narrower gap results in a significant decrease in the voltage difference between the anode and the cathode, thus improving energy efficiency. This can result in up to 20% electricity saving compared to a conventional cell [115]. For the Dutch situation, this would imply an electricity saving of approximately 2.5 PJ_e. To date, a major cause for the lack of succes in producing titanium diboride cathodes has been material failure. Recent progress in this field suggests however that these problems could be overcome through a combined titanium diboride - graphite cathode.

Inert anodes

The current Hall-Héroult cell uses carbon anodes that are oxidised in the aluminium production process (see Section 4.1). In principle, the anode oxidation can be avoided if a suitable inert material can be found. In such a case, the production and consumption of carbon anodes could be avoided. In the Dutch case, this would imply a reduced consumption of oil products of up to 15 PJ primary energy (see Section 2.5). Unclear is however the impact of inert anodes on the electricity consumption. The evolution of oxygen is at the expense of increasing the cell voltage by approximately one volt. However, if the simplicity of bipolar drained cell designs can be utilized, voltage savings can be made by eliminating ohmic effects associated with ancillary circuitry. Optimistically, it may be hypothesised that the oxygen over-voltage will be significantly lower than that for evolving carbon dioxide [116]. There may be some double accounting in this assessment, as the same savings are claimed for the new cathode technology.

However, introduction of inert anodes seems currently even further away than the introduction of new cathode materials. The problems with anode stability pose still a major obstacle. It is still unclear if these problems can be solved in the next two decades.

Increased aluminium scrap recovery

Table 10.1 lists the waste balance for Dutch aluminium waste in 1994. The table shows that from the total amount of post consumer waste, only 61% was recycled in 1994. The bulk of the losses are aluminium foils, aluminium laminates and aluminium cans in household waste and similar waste from offices, shops and the service sector, which cannot be cost-effectively collected. As a consequence, they end up in waste combustion plants. Larger aluminium parts are separately recovered and recycled.

Separate collection of the remaining aluminium waste fraction seems no viable option. One should however mention the separate aluminium can collection system in the United States. This option may not be feasible in the Netherlands because the aluminium can consumption is per capita 10 times lower than in the US. The higher minimum wages in the Netherlands make the labour intensive separate collection unattractive. Centralised collection systems for a PMB-fraction (plastics, metals and beverage containers), similar to the existing glass container collection structure, may pose a viable alternative. Separate collection can increase the aluminium content from 0.5% in MSW to 1.5% in the PMB fraction. Deposits may also be an alternative to increase recycling. Such approaches would however imply more handling by the consumer and the retailer, contrary to the ongoing trends.

The aluminium fraction can also be separated in waste combustion plants before or after the combustion process. This separation is based on the Eddy Current technology, where rotating magnets are used for separation of aluminium from the remaining waste fraction. This method seems attractive for waste types with high aluminium content, like foils and cans. It is less attractive for laminates, which contain only 10% aluminium. They can only partially be recovered from the waste streams. Laminates represent approximately 5 kt of aluminium waste per year. The remaining fraction consists of beverage and food cans (total 7 kt), pure foils (2.1 kt), 1.1 kt spray containers etc. and 0.7 kt aluminium lids (1989 figures [117].

The efficiency of Eddy Current separation depends to a large extent on the diverging shape of the particles and the configuration of the magnets. Assuming that laminates cannot be recovered, the potential for additional aluminium recovery is approximately 25 kt per year (see Table 10.1); the energy saving, based in the energy consumption data in Section 4.1 and 4.2, is approximately 3.9 PJ primary energy per year. The costs of this improvement option are still unclear, but are probably high due to the significant effort to remove small amounts of aluminium from large amounts of other waste. As the major part of the costs are capital costs, the aluminium content of the waste will determine the economic viability of any separation scheme. The price of an Eddy Current separation plant for 25 kt waste per year is approximately 390.000 guilders [118]. Depreciation and variable costs result in an annual cost of 153.000 guilders. The aluminium content of the waste is 0.5-1.5%, the value of the aluminium scrap is approximately 500 guilders per tonne. The yield is 62.500 to 187.500 guilders. In the second case, the price of the PMB collection scheme must be added. The additional costs are probably small, if the existing glass containers are replaced by PMB containers. It remains to see what the collection efficiency will be in such a scheme. If the aluminium is recovered from MSW, the net cost is approximately 725 guilders per tonne recovered aluminium scrap.

With regard to the energy saving, increased aluminium waste recovery will probably not result in decreasing primary aluminium production in the Netherlands, but instead result in additional secondary aluminium production [119].

Table 10.1 *Aluminium waste balance, the Netherlands, 1994 [120]*

Waste category	Total waste [kt pa]	Loss [kt pa]	Recycling fraction [%]
Household waste (regular)	14.2	14.2	0
Household waste (large fractions)	7.7	5.5	29
Offices/Shops/Service waste	8.5	6.5	24
Industrial waste	8.1	2.5	69
Construction/demolition waste	10.0	0.6	94
Shredder waste (cars)	30.0	1.7	94
Cleaning services	1.1	1.1	94
Recovery after MSW combustion		-1.2	
Total post consumer	79.6	30.9	61

10.2 Steel

New technologies for steel production have been the subject of significant research efforts in the last decades. The main goal of this research was reduction of blast furnace coke consumption, as many companies face replacement of the coke ovens, which is a very costly investment. Two main alternative steel production routes exist for the blast furnace and scrap based EAF production. A new category of processes are so-called smelting reduction processes that serve as replacement of the whole route from coke production, sinter, pellet production to the blast furnace. Direct reduction processes yield solid direct reduced iron (so-called sponge iron or DRI) that can be shipped and is further processed in electric arc furnaces. In this case, the DRI/EAF combination replaces the BF/BOF combination. Two examples of smelting reduction processes and one DRI production process will be discussed in more detail in this section. For a detailed overview of the technologies and their merits, one is referred to the literature (e.g. [121]). Apart from new supply technologies, two completely different energy saving options will be discussed, namely increased steel scrap recovery and dematerialisation through an increased focus on products with higher added value.

In future years, reduction of CO_2 emissions may prove another important incentive for changes in the steelmaking process. The impact of CO_2 reduction on the future attractiveness of technologies will be discussed in Chapter 12. Another important research area concerns the development of new steel types (see Chapter 3). This research area will not be discussed in this section.

Four issues will be discussed in this section:
a. short term energy efficiency improvements
b. new steelmaking technologies
c. increased steel scrap recovery
d. dematerialisation.

a. Short term energy efficiency improvements

The discussion in this section focuses on:
- recent and near term energy saving measures
- plastic waste injection
- substitution of biomass for coal
- near net shape casting.

These options are all proven technologies that are used in other countries and that can be applied within the current production process of Hoogovens.

Table 10.2 provides an overview of short term efficiency improvement options for Hoogovens that have been suggested in recent years. Most cost-effective options in Table 10.2 have been introduced since 1992. The options that have not been implemented are either costly or technologically problematic.

Current energy efficiency improvements are embedded in the long-term convenant regarding energy efficiency, which has been discussed in Section 2.5.

Table 10.2 *Short term energy efficiency improvement options for Hoogovens in 1992 ([76], adjusted)*

Option	Savings [PJ/year]	Costs [NLG/GJ]	Status
BOF-Oxygen‘speicher’	0.02	-10.3	Implemented
Good housekeeping	0.35	-8.4	Implemented
Expansion turbine	0.02	-4.9	Implemented
Direct coal injection	0.21	-3.6	Part. implemented
Slabbing furnace	0.05	-2.0	Not implemented
Hot strip mill-heatpump	0.10	-0.3	Implemented
BOF-gas recovery + closed OG	1.30	0.0	Implemented
EL: speed control devices	0.11	8.3	Not implemented
Waste heat recovery	0.52	12.9	Not implemented
Dry coke quenching	0.33	14.0	Not implemented

With regard to Nedstaal, energy efficiency measures representing 23% of the current primary energy use have been identified, provided the ingot casting practice is not changed into continuous casting [77]. The major part of these savings affects the product quality or features a pay-back time of more than 7 years. As a consequence, the attractive energy efficiency potential is much more limited. Because of the limited importance of Nedstaal for the Dutch energy system, these measures are not discussed in more detail.

An interesting option for energy saving at Hoogovens is the injection of plastic waste in blast furnaces. Oil injection has been widely applied for blast furnaces in the 70’s, but was abandoned because of the rising oil price. Plastic waste can substitute oil [122]. It has a similar heating value, and can be injected into the blast furnace. Before plastic waste is added, the chlorine content must be reduced by degradative extrusion. The molten plastic can be injected into the blast furnace, similar to the oil injection. Because plastic waste is not considered as an energy carrier, this option results in a substantial reduction of the energy consumption. Assuming an availability of 120 kt plastic waste, the potential is approximately 5 PJ. Coal is substituted on a thermal par basis. Most research in this area is currently going on in Germany at the Klöckner steel plant in Bremen, where 210 kt plastic waste will be processed in the next 3 years [123]. The cost-effectiveness of this option is however limited by the availability of plastic waste. The German situation is somewhat different because the separate collection of (plastic) packaging waste is mandatory within the framework of the packaging waste legislation.

Increased plastic waste use at Hoogovens implies less plastic waste incineration in MSW incineration plants or less plastic waste recycling. Similar to increased scrap use, this is an option with considerable a lower saving potential from a global point of view (2-3 PJ per year).

Another interesting option is the use of charcoal (a biomass product) as a substitute for coal. Approximately 7 Mt iron production (1.2% of the annual global production) is based on the use of charcoal instead of fossil coal. This production is for 95% concentrated in Brazil. Biomass can substitute the CO_2 intensive coal, resulting in steel production that is based on renewable energy sources. As charcoal has a much higher energy content than biomass (29 GJ/t vs. 17 GJ/t), transportation costs for charcoal are per GJ lower than for biomass. Import of charcoal is in line with the policy plans to import renewable biomass into the Netherlands from countries with lower production costs. The conversion of biomass to charcoal is a similar pyrolysis process as the production of coke from coal. The energy yield is approximately 56% for charcoal and 25% for other liquid and gaseous products. The charcoal price will depend on the biomass price, the value of by-products and the conversion costs. Assuming biomass costs of 3 guilders per GJ (a production price for e.g. Brazil) and a price of 5 guilders per GJ for the by-products (a conservative estimate) and conversion costs of 3 guilders per GJ, the charcoal production price would be 4.8 guilders per GJ. If the transportation costs for charcoal from Brazil to the Netherlands are 1 guilder per GJ (a high estimate for bulk transportation from Brazil, see Table 5.6), total costs for use in the Netherlands would be 5.8 guilders per GJ. This charcoal can even substitute coke. If it is assumed that charcoal substitutes coal injection, the additional costs are approximately (5.8-3) = 2.8 guilders per GJ substituted coal. The CO_2 emission for coal combustion is 0.094 kg/GJ, so this CO_2 reduction measure would cost 30 guilders per tonne CO_2, a cost level that seems very attractive from a CO_2 policy point of view. This assessment does not yet include any impacts on the production rate of the blast furnaces. It is yet unclear if this production rate will be reduced. Such a reduction may result in additional costs. The implementation of this option is also limited by the availability of renewable biomass; currently only 40-50% of the biomass used for iron production in Brazil is derived from plantations, the remainder is still harvested from natural forests. The option is not analysed in any more detail but is only mentioned to illustrate the flexibility of steel producers to cope with CO_2 and sustainability issues.

One option in the rolling section currently widely discussed is thin strip casting. Currently a 225 mm slab is cast and subsequently cooled and fed into the rolling mills. New technologies allow the casting of slabs with a thickness of 50-80 mm. Examples are the compact strip production process (CSP) and the in-line strip production process (ISP). They save approximately 50% of the current hot rolling energy requirement (1-1.2 GJ/t) and save up to 70% of the rolling costs (a cost reduction of 125 guilders) [124]. This technology is currently applied at NUCOR (USA), Arvedi (Italy) and a number of Japanese companies (Nippon steel etc.) [125]. Hoogovens has recently announced its plans for construction of a new thin casting plant with a capacity of 1.5 Mt per year [126]. The total investment costs are 500 million guilders.

On the longer run, casting of even thinner material (in the range of 1-5 mm) could further reduce the energy consumption for rolling. Such technologies are however not yet proven on a commercial scale. The main problem is that the physical steel characteristics are currently largely determined in the rolling section. Finishing processes without rolling will influence the materials quality. No introduction on a commercial scale is expected in the next two decades.

b. New steelmaking technologies

New iron and steel production technologies are currently developed in order to replace coke ovens and ore agglomeration. This research is cost and strategy driven, but it may in some cases also reduce energy consumption, because coke production and agglomeration require considerable amounts of energy.

Steel production technology is currently rapidly evolving. Decreasing demand in industrialised countries results in heavy competition. As a consequence, quality and custom made products become increasingly important in order to compete with other materials and with other steel producers. Another strategy to remain competitive is cost reduction. In order to decrease costs, steel producers search for technologies to produce steel with coal as energy source instead of coke. The coal injection into existing blast furnaces is already the first step into this direction, but new technologies can completely replace the costly coke production. Some sources suggest also that coking coal and steam coal price differences may increase. Differing trends would result in increasing cost advantages for processes that can use steam coal. The historical price data in Figure 7.4 suggest however no widening price gap in the last 15 years, so a widening gap is not taken into account in this analysis.

Another expensive operation in current steel plants is the production of sinter and pellets. If iron ore fines can be used instead of agglomerated ore, this will result in additional cost savings. Apart from the cost saving, an additional advantage of the new processes is that their size is generally smaller and their output can be more easily adjusted. This allows more readily adjustment of the output to the market conditions. On the other hand, it may also facilitate new producers to enter the steel market.

With regard to the scrap recycling in mini-mills, the main technology drive is the reduction of the electricity consumption and increased productivity of the installations. The options are scrap preheat (e.g. the Consteel process) and addition of coal and oxygen to the furnace (e.g. the Danarc process) [83]. The Energy Optimising Furnace (EOF) is a concept where the furnace is completely heated with coal and oxygen, and the scrap is pre-heated with the off-gases from the furnace. Some options like Consteel can also be implemented at the existing Nedstaal furnaces. A reduction of the electricity consumption of the furnaces to values below 1 GJ/t seems feasible through introduction of new scrap processing technologies (see also Table 6.2 for data regarding the new Contiarc scrap recycling concept). Because the energy consumption of the Nedstaal furnaces is of limited importance for the Dutch energy system, these options will not be discussed in more detail. Generally speaking, increased scrap recycling is favourable from an energy consumption point of view, independent of the applied technology.

Smelting reduction
The smelting reduction process can be split into a coal gasification step and an ore reduction step that uses the coal gas. The ideal concept of a direct-smelting reduction process to convert fine ore and coal to liquid iron has not been realized yet. The only smelting reduction process that is currently applied on a large scale is the Corex process. This process can be used for production of high quality liquid iron from low quality coal and iron ore pellets. Hoogovens opts for a new process, called the cyclone converter furnace (CCF). The CCF concept may have an advantage because the concept is based on the use of iron ore fines and coal.

Other smelting processes have been under development, e.g. in Japan (the DIOS process), in Australia (the HI-smelt process) and in the US by the American Iron and Steel Institute (AISI) [127]. All three research projects have not (yet) resulted in new process technologies that can be applied on a commercial scale.

The smelting reduction concepts differ in the technological approach, the main idea is in all cases to replace coke production and possibly the iron ore agglomeration. Original plans were even to replace the steelmaking step, but this idea proved to be infeasible up till now.

Cyclone converter furnace (CCF)
The CCF is a process that is currently developed by Hoogovens. The goal is produce liquid iron from steam coal and iron ore, avoiding the coke making process and the ore agglomeration [128].

The two-stage process consists of pre-reduction and pre-melting of iron ore in a melting cyclone, followed by final reduction in a converter type vessel containing a liquid iron bath. Both stages of the process are combined in a single reactor. Both process stages have been proven on a benchscale. The integrated process is currently considered for upscaling to a pilot plant scale (0.5-1 Mt per year). It remains to prove if the process can be developed successfully, given the obstacles that have been encountered abroad during the development of other smelting reduction processes.

In the CCF process, ore and oxygen are injected tangentially into the melting cyclone. The melting cyclone is mounted on top of a converter type vessel. The pre-reduced molten ore is collected on the wall of the cyclone and flows into the bath. The final reduction of the ore and gasification of granular coke take place in the iron bath. About 25% post combustion with 80% heat recovery is required in order to cover the heat requirement in this stage of the process. The pre-reduction degree of the iron (in the cyclone) is 25%. The gases arising from the smelter are further combusted in the melting cyclone in order to generate melting and pre-reduction heat. The final combustion rate of the offgases is 75%.

The energy balance for the CCF process is shown in Table 10.3 (based on 25% post combustion, 80% heat recovery above the iron bath, hot metal with 4% carbon at 1500°C, a slag basicity of 1.1 and an exit gas temperature of 1800°C, excluding oxygen production). The process generates significant amounts of energy by-products. The economy of the process depends to some extent on the value of these by-products (see Chapter 11 and 12). The data in Table 10.3 are preliminary estimates. Recent preliminary calculations indicate that the actual energy consumption may prove to be somewhat lower, with a higher ratio of gas to steam by-product.

Table 10.3 *Energy and mass balance of the CCF process ([128], adjusted)*

Input		[GJ/t iron]	Output		[GJ/t iron]
Coal	640 kg	20.1	Hot metal	1000 kg	9.9
Ore	1500 kg		Slag	270 kg	0.4
Oxygen	730 kg		Gas	1214 Nm^3	4.0
Lime	110 kg		Steam		4.3
			Losses		1.4
Total		20.1			20.1

Corex

The Corex process is a proven concept for smelting reduction. It is currently applied in South Africa in plant of 300 kt pa capacity. Three larger Corex plants are currently under construction in South Korea. Lumps of iron ore, pellets and sinter are reduced in a reduction shaft that is fed with reducing gases from the smelting vessel. In the process, a mixture of FeO and Fe_2O_3 is generated. The coal is added to the smelting vessel, where the iron is completely reduced. The iron quality is similar to the iron quality from blast furnaces. Oxygen is used for the gasification, together with air in order to keep the off-gas temperatures below 1750°C in order to prevent excessive wear of equipment. The process can use bituminous coal in pieces of 0-50 mm. Off-gases are pure and can be used for power generation. The main advantage compared to the blast furnace is that coke production can be avoided and a lower coal quality can be used. Compared to the CCF process, the ore palletising step represents an additional expenditure. Corex plant capacity is similar to the CCF process capacity. It is unclear which process has the highest maintenance requirements. The Corex process has currently clearly an advantage over CCF, as the process is proven on a commercial scale.

Table 10.4 shows that emissions from both Corex and CCF are significantly lower than emissions for the blast furnace process. The value of these advantages may be an important incentive to shift the balance to the new processes. For CO_2, this advantage will be analysed in Chapter 12.

Table 10.4 *Emissions for blast furnace, for Corex and CCF (includes all emissions from raw material preparation onwards) [kg/t hot metal] [129]*

	Blast furnace	Corex	CCF
NO_2	1.91	0.02	<0.02
SO_2	1.59	0.03	<0.03
Dust	0.43	0.04	<0.04
CO_2 [1]	1700	1300	1200

[1] Excludes CO in off-gases.

Concerning the Corex energy balance, data for the process are shown in Table 10.5. One should add that there is a significant technological 'window' where the Corex and the CCF process can operate. This window is determined by the post-combustion rate and the pre-reduction ratio [130]. The minimum coal consumption rate for Corex is achieved at a post-combustion rate of 50% and a pre-reduction ratio of 30-33%: 850 kg for a coal with 14% ash content and 57% fixed carbon content.

Compared to CCF, the oxygen consumption rate of Corex is somewhat lower, while slag formation is somewhat higher. These differences are probably related to slightly differing coal types for the process data in Table 10.3 and 10.5.

Table 10.5 *The Corex energy balance [131]*

Input		[GJ/t iron]	Output		[GJ/t iron]
Coal	950 kg	29.0	Hot metal	1000 kg	9.9
Ore	1500 kg		Slag	300 kg	0.4
Oxygen	714 kg		Gas		10.9
Lime	110 kg		Steam		6.4
			Losses		1.4
Total		29.0			29.0

One should add that the comparison for CCF and Corex with the blast furnace depends to a large extent on the coal, coking coal and coke prices and the value of the by-products gas and steam. The competitiveness of these three processes is discussed in Chapter 11 and Chapter 12.

Direct reduction

Direct reduction processes are similar to the smelting reduction in the CCF and Corex processes. The difference is that the partially reduced iron is not immediately converted into liquid iron, but is sold as solid resource for further processing in blast furnaces or in electric arc furnaces.

In the DRI process iron ore in the form of fines or agglomerated products is reduced in the solid state using gaseous reductants produced from natural gas, oil or coal. The reduction is carried out below the melting point of iron (approximately at 900°C). The reduced product known as sponge iron or direct reduction iron (DRI), has low carbon content but still contains the impurities from the ore and is primarily used as a charge to electric arc furnaces.

Sponge iron has a 90-95% degree of metallization and 1.5% carbon content. Sponge iron can be further processed in electric arc furnaces. It can be used to prevent scrap shortages or to enhance the steel quality from EAF production. DRI is a relatively pure material which dilutes contaminants in the scrap and improves the steel quality (see Table 6.4). Direct reduction is already widely applied, especially in countries with low gas prices like Mexico and Indonesia. The gas based Midrex and HYL processes cover currently 90% of the DRI production. The world DRI production amounted to 23 Mt in 1993 (2.5% of the world steel production).

Natural gas is most widely used to produce DRI. It is also possible to couple coal gasification and DRI production. In [132], investment costs for such a combined plant are estimated to be 290 NLG/t sponge iron capacity. These investment costs are in between the investment costs for the CCF and the Corex process. It is also possible to process coal lumps and pellets in a rotary furnace for DRI production. The advantages of DRI production with coal, compared to smelting reduction, are however unclear (may be increased flexibility, because DRI can be stored).

Table 10.6 *The DRI energy balance (product 92% metallisation, 2% carbon content) [131]*

Input		[GJ/t iron]	Output		[GJ/t iron]
Natural gas		10.7	Hot DRI	1000 kg	9.0
Electricity		0.3	Losses		2.0
Ore	1500 kg				
Total		11.0			11.0

DRI requires expensive processing in EAF furnaces, while liquid iron can be processed in BOF plants. The natural gas based DRI/EAF route for steel production has an advantage because it has lower CO_2 emissions than the smelting reduction/BOF or blast furnace/BOF route. On top of this advantage, CO_2 removal costs would be lower because CO_2 is currently already removed in order to allow the recycling of off-gases. CO_2 removal is also possible with off-gases from blast furnaces, Corex plants and CCF plants. This requires however an additional plant for CO_2 removal. Both advantages of the DRI process may on the long term prove to be important advantages (see Chapter 12).

The costs for CO_2 removal and storage are analysed in Table 10.7 and 10.8. No detailed studies with regard to CO_2 removal in the steel industry have been found. Data are based on calculations for coal fired power plants. Table 10.7 compares the gas composition for ICGCC, BF, Corex and CCF. The figures show that the aggregated carbon monoxide and CO_2 content for Corex and CCF is approximately the same as for a coal gasifier. For a blast furnace, concentrations are lower because of the dilution with nitrogen. Lower concentrations will probably increase the removal costs. On the other hand, the scale of operations is larger for blast furnaces. This will reduce removal costs. Even for the blast furnace, concentrations are well above the levels for the conventional coal fired power plant. As a consequence, removal costs will be lower. Table 10.8 shows the assumptions with regard to the CO_2 removal costs.

Table 10.7 *Composition of gas flows [%] [133,134,135]*

Component	Shell gasifier	Coal fired power plant	Blast furnace	Corex	CCF (est.)
Hydrogen	30	0	3	15	5
Carbon monoxide	64	0	21	40	40
Carbon dioxide	1	13	20	35	45
Methane	0	0	0	1	0
Nitrogen	4	72	56	9	10
Other	1	15	pm	pm	pm

Table 10.8 *Costs for CO_2 removal and storage (estimated on the basis of [136])*

Process	Efficiency [%]	Removal [NLG/t]	Transport + storage [NLG/t]	Total [NLG/t]
Blast furnace	80	50	10	60
Corex	90	30	10	40
CCF	90	30	10	40
Hyl	95	0	10	10

DRI requires further processing in EAF furnaces. Some authors suggest that the DRI price must be compared with the price of steel scrap (180 NLG CIF 1993) instead of with the price for iron ingots (approx. 300 NLG CIF 1993). A recent study states that DRI can be imported into Western Europe from Venezuela for 210 NLG per tonne, while production costs in Western Europe are estimated to be 275 NLG per tonne [137]. The DRI price is still above the scrap price, but DRI has an advantage because it contains less contaminants (Table 6.4). As a consequence, there is a quality bonus in certain markets where scrap based steel cannot be used. The price of DRI seems low enough to merit further analysis of the DRI/EAF route for medium and high quality steel production.

In conclusion, the following model structure in Figure 10.1 will be studied in more detail in the sensitivity analysis (Chapter 12).

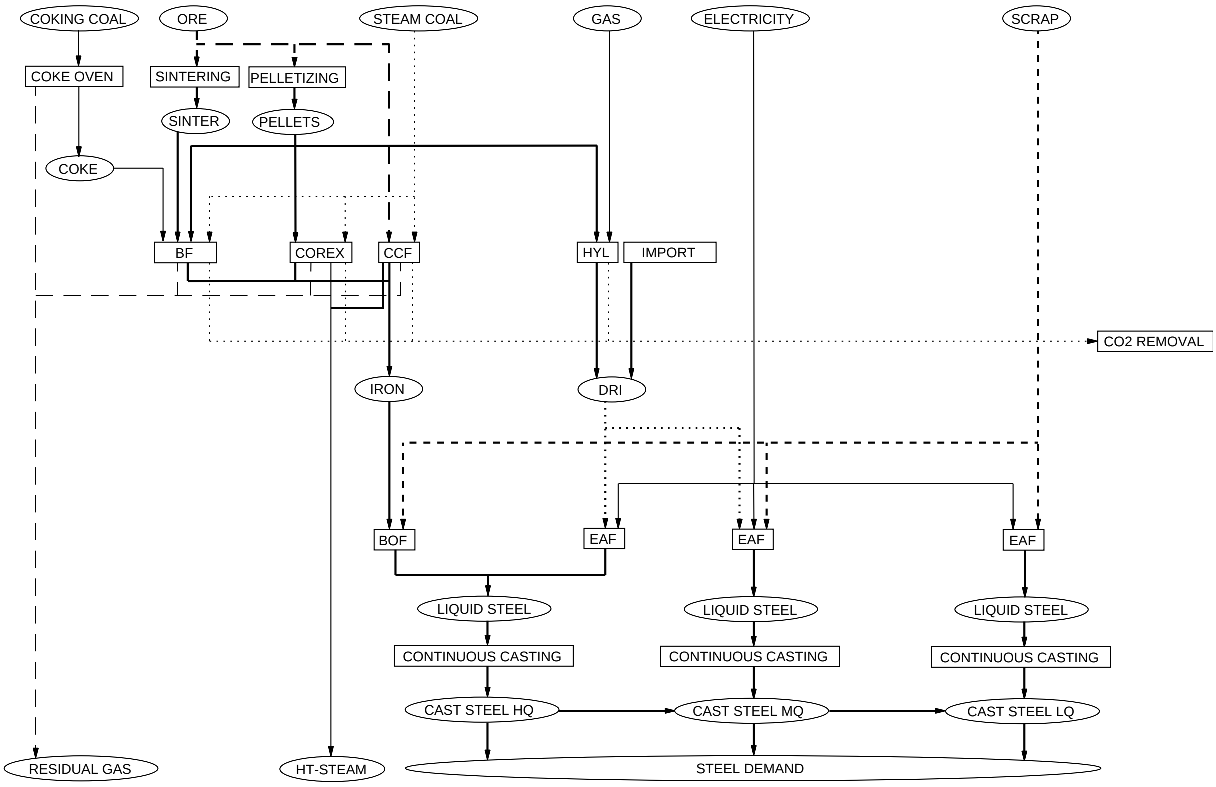

Figure 10.1 *Steel model structure (HQ= High quality steel; MQ = medium quality steel; LQ = Low quality steel)*

This structure should be considered a simplification of the actual situation. For example, interesting combinations of smelting reduction and DRI production are also possible. The South Korean HANBO corporation has been constructing a new Corex plant. The off-gases from this plant are used for production of DRI. The cost advantage of such combinations is obvious (cheap coal based gas for DRI production, without additional costs for gasification), but it is still too early to judge its technological merits (eg the drawback of increased inflexibility).

Figure 10.1 shows also only one quality of residual gas. In reality, the heating value of the residual gases differs to a large extent (see Table 10.9). These different gas qualities cannot be used for all applications (or only with different efficiencies). As a consequence, their value may differ. However, no references were found with regard to this problem. As a consequence, they will be compared on a thermal par basis.

Table 10.9 *Residual gas qualities for different processes*

Gas type	Lower heating value [MJ/m^3]
Coke oven gas	20
Blast furnace gas	3.5-4
BOF gas	9
Corex gas	7-8
CCF gas	4
Natural gas	32

Figure 10.1 shows a quality cascade for the steel market. Three steel qualities are discerned, substitution is only possible from high to medium to low quality. The difference between high quality, medium quality and low quality steel in Figure 10.1 is made because of the possibility to use high quality steel for the outside cladding of vehicles, packaging applications, structural elements, tubes and (part of) the machinery production. Applications like reinforcement bars, household equipment, furniture have lower quality requirements. Quality depends in this analysis only on the impurity content (see Table 6.4). Because only one scrap quality is considered, the results in Chapter 12 can only provide general insight in the potential of DRI and scrap recycling in a steel market that is actually split in a number of separate market segments. Based on the product prices in Table 7.1, the quality bonus for high quality steel is approximately 200 NLG per tonne. This bonus is off course only valid for the markets where the scrap based steel cannot cope with the quality requirements.

Ore based steel production (blast furnaces, Corex, CCF, DRI) results in a low impurity level. This steel can serve the high quality market. Scrap based steel production results in high levels of impurities. In certain markets, scrap quality can be sufficiently upgraded by addition of DRI. One should emphasize that data with regard to market segmentation are scarce; the model data are based on estimates. It is assumed that the quality requirements will increase in coming decades, resulting in a shift from low quality to medium and high quality steel.

Note also that some energy flows of lesser importance like the coke breeze use for sintering, electricity use for palletizing and tar production from coke ovens is not shown in Figure 10.1 for graphical reasons. These flows are however taken into account in the sensitivity analysis in Chapter 12.

c. Increased steel scrap recovery

Increased recovery of steel scrap is an option to reduce energy consumption in the steel sector. Table 10.10 shows the current steel waste recovery rates and the remaining recovery potentials in the Netherlands. The potential for increased recovery is estimated to be 452 kt. This represents according to Chapter 6 a potential of 13 * 0.452 = 6 PJ primary energy. The waste figures in Table 10.10 are however rather uncertain. Significant amounts of used products may be exported (e.g. cars, refrigerators, ships). More detailed research is required in order to gain more insight into the still existing recovery potential.

Table 10.10 *Steel waste balance, the Netherlands, 1994 [138]*

Waste category	Total waste [kt pa]	Loss [kt pa]	Recycling [%]
Packaging	209	93	56
Other household equipment	360	176	51
Transportation equipment	400	43	89
Production waste	625	65	90
Construction/demolition waste	290	75	74
Total post consumer	1884	452	76

Combination of the data in Table 10.10 and the data in Figure 3.5 shows that despite the stabilising steel consumption, a total shift to scrap based EAF steel production cannot be expected. The European scrap arising is smaller than the steel production because of the significant exports of steel, steel containing products and steel scrap. The still increasing steel stock in long life buildings and their interior explains also an important part of the imbalance. The current losses out of the steel materials system due to disposal and oxydation are only of minor importance.

d. Dematerialisation

The trend towards increased product quality counteracts energy saving trends to some extent, because increased quality implies often increased processing, which results in increased energy consumption per unit of physical production. These trends tend however to save energy per unit of added value, because the price per unit of physical production increases significantly (see Chapter 7). In the last decade, new processing units at Hoogovens included a vacuum pan oven for secondary metallurgy (+0.5 GJ/t treated steel) and a galvanising line (+0.3 GJ_e/t galvanised steel). The product mix shifts from slabs and hot rolled sheet to more cold rolled and coated products. The thickness of the sheets is also a relevant parameter, because the amount of energy that is necessary for rolling is related to the production in m^2 (see Figure 6.2). The energy efficiency potential per mass unit is to some extent counteracted by such additional operations.

11. COMPARISON OF INTERNATIONAL PRODUCTION OPTIONS

Several plant locations and energy carrier types are now compared and analysed in more detail, based in the selection in the preceding paragraphs. All plants produce aluminium ingots and crude steel, respectively. Comparison is based on one tonne of aluminium ingot or one tonne of semi-finished steel delivered in the Netherlands.

The following options are compared for aluminium:
1. primary aluminium smelter, Netherlands
2. primary aluminium smelter, Venezuela
3. primary aluminium smelter, Iceland
4. aluminium recycling, Netherlands
5. aluminium recycling, Poland.

The following options are compared for steel:
1. Blast furnace, Netherlands
2. Blast furnace, Australia
3. Corex, Netherlands
4. Corex, South-Africa
5. CCF, Netherlands
6. DRI-EAF (natural gas based), Netherlands
7. DRI-EAF (natural gas based), Venezuela
8. DRI-EAF (coal based), South Africa
9. DRI-EAF (coal based), Australia
10. Steel scrap recycling, Netherlands
11. Steel scrap recycling, Turkey.

The concept for aluminium is that ingots can be traded in an international market, so the aluminium ingot producers can be separated from the aluminium processing. For primary steel, materials quality is very important. This quality is determined in the BOF/EAF process. As a consequence, total control of the steel production process (from iron to finished steel) by one producer is required. Hoogovens could control the process by production of iron ore, DRI or finished steel abroad. EAF and primary steel production cannot be compared straightforward because of differing product qualities, but EAF production in Turkey and the Netherlands can be compared. General data for energy prices are shown in Table 11.1. General data with regard to labour costs are listed in Table 11.2.

Table 11.1 *Energy price assumptions [NLG/GJ] (excl. electricity for aluminium)*

Type	Netherlands/ Poland	Venezuela	Australia	Turkey	South Africa
Steam coal	3	-	1.5	-	1
Pulverized steam coal	3.5	-	2	-	1.5
Coking coal	3.5	-	3.5	-	3.5
Natural gas	6.4	1	1	-	-
Other residual gas	6.4	0	0	-	0
Electricity	25	10	10	10	10

Data with regard to labour costs are scarce. It is assumed that in all countries that are studied as investment site, local employees can be hired. The wage level differences are probably less extreme than the average wage differences, because skilled labour is required. Labour productivity is probably somewhat lower in countries with lower wages. This will also decrease the labour cost gap. The best comparison would be based on actual labour cost data for each specific project on each specific site. These data are however not available. Table 11.2 lists labour costs in the Netherlands and abroad, where the labour costs are adjusted for labour productivity.

Table 11.2 *Labour cost estimates for different countries*

	Industrial labour costs [NLG/hr]
Netherlands	40.0
Australia	50.0
Iceland	50.0
Poland	10.0
South Africa	10.0
Turkey	10.0
Venezuela	10.0

Table 11.3 *Transportation costs to the Netherlands*

Production country	Product	Freight costs [NLG/t]
Australia (Pilbara coast)	Iron ore	12
	DRI	12
	Steel slabs/billets	75
South Africa (Highveld inland)	DRI	20
	Steel slabs/billets	60
Venezuela (Puerto Ordaz)	DRI	10
	Steel slabs/billets	50
	Aluminium ingots	50
Iceland	Aluminium ingots	30
Turkey (Samsun coast)	Scrap	10
	Steel slabs/billets	40

Table 11.4 lists relative investment costs in different countries. Investment costs differ because of differing scope of the project (eg lacking infrastructure) and because of different price setting for equipment, eg because of lacking local equipment manufacturers.

Table 11.4 *Relative investment costs at different sites*

Country	Relative investment costs
Netherlands	1.00
Australia	1.25
Iceland	1.50
Poland	1.00
South Africa	1.25
Turkey	1.25
Venezuela	1.50

11.1 Aluminium

The essential difference in aluminium production costs is caused by the different electricity prices. They are compared in Table 11.5.

Table 11.5 *Estimate of electricity prices for aluminium smelters ([62], adjusted)*

Country	Electricity price [NLG/kWh]
Netherlands	0.07
Venezuela	0.04
Iceland	0.05

One should add that the prices in Table 11.5 are own estimates. Electricity prices for aluminium smelters are generally arranged in confidential contracts. They are well below the electricity prices for the other industries. Venezuela and Iceland are countries with high potentials for hydroelectricity and geothermal electricity, respectively. The low electricity price in the Netherlands will probably rise in future years due to the closure of the nuclear plant in Borssele.

The production costs for the different production locations are compared in Figure 11.1.

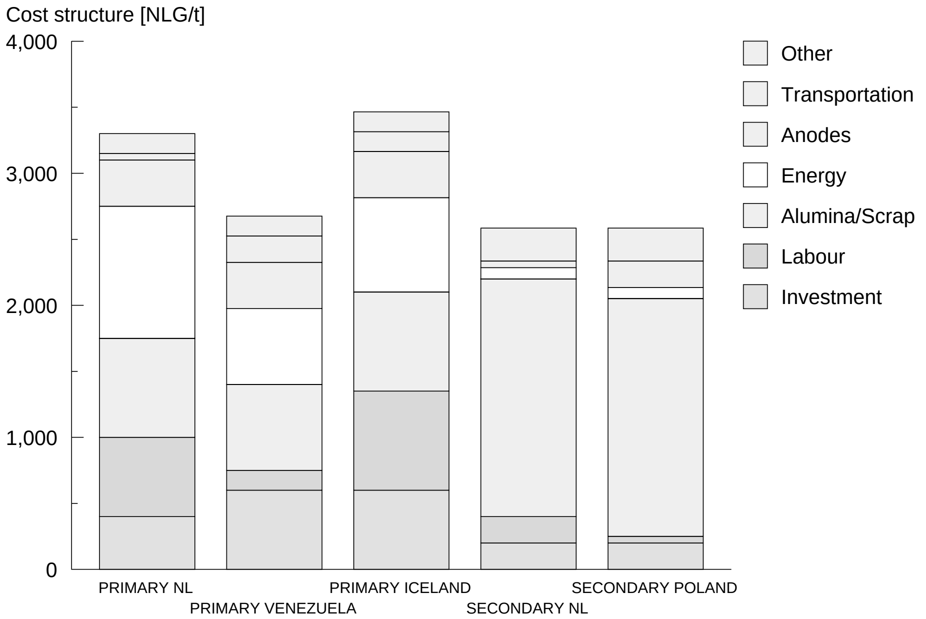

Figure 11.1 *Production costs for aluminium for the Western European market*

The investment costs of the smelter depends on the local circumstances. If the equipment must be imported or if additional facilities like roads and power lines must be constructed, the price of the smelter is higher. It is assumed that the Venezuelan and Iceland smelter are 50% more expensive than the Dutch smelter.

The transportation costs must be added to these production costs. Figure 11.1 provides an overview of the production costs for the European market (excluding import levies etc.). According to the results in Figure 11.1, the cheapest production is possible in Venezuela. The other two sites for primary aluminium production show only small variations in production costs that are not significant, given the uncertainty in this analysis.

Special attention should be paid to levies for imports from countries outside the European Union. Import levies must be added to these cost prices. Import levies are zero if the exporting country can issue an 'Eurocertificate'. If the country is not willing to issue this certificate, the levies in Table 11.6 are applied. Producers from the USA, Canada and the Gulf nations must pay the 6% import levy.

Table 11.6 *Import levies without Eurocertificate*

SITC code	Type	Import levy EU-15 without Eurocertificate [%]
760110000	Primary aluminium ingots	6
760120100	Primary aluminium alloys	6
760120900	Secondary aluminium alloys	6
760429900	Aluminium alloy profiles	8.5
761090900	Other aluminium constr.	6.4

11.2 Steel

This paragraph discusses the production costs for liquid iron and steel slabs. Liquid iron is an intermediate in the integrated steel production that cannot be sold, but it may serve for comparison of technologies in processes where liquid iron is an intermediate (blast furnaces, Corex and CCF, see Chapter 10). For DRI based EAF and scrap based EAF, liquid steel is no intermediate. As a consequence, comparison with these technologies must include all steps that are required for steel production.

The assumptions regarding resource prices are shown in Table 11.7. The process characteristics in Table 11.8 refer to the individual processes. The total investments costs for the blast furnace route are significantly higher because the coke ovens must be added (see Table 7.2).

Table 11.7 *Resource price assumptions [NLG/t]*

Type	Netherlands [NLG/t]	Venezuela [NLG/t]	Australia [NLG/t]	Turkey [NLG/t]	South Africa [NLG/t]
Iron ore	37	25	25	-	25
Oxygen	50	75	62.5	-	62.5
Steel scrap	200	-	-	225	-
BF slag	28	10	10	10	10

Table 11.8 *Capital costs and labour costs of different steel production technologies*

		All	Blast furnace	BOF	Corex	CCF	DRI	EAF
Interest rate	[%]	8						
Utilization	[-]	0.8						
Life	[years]	30						
Annuity	[-]	0.09						
Investment costs	[NLG/t cap][1]		150	200	200	200	200	100
Labour	[hr/t]		0.4	0.4	0.5	0.5	0.4	0.6
Maintenance	[NLG/t cap.year]		6	8	10	15	5	4

[1] Excluding coke oven, ore agglomeration plants, oxygen production.

The investment and maintenance costs for the electric arc furnace in case of the DRI-EAF route are 30% lower because the production rate is higher in case DRI is used [139].

Figure 11.2 shows the production costs for molten iron in the Netherlands for the blast furnace, Corex and CCF plants. The costs of the process inputs are indicated as positive values, the value of by-products is indicated as negative costs. The figure indicates the following net production costs for liquid iron: 226 NLG per tonne for the blast furnace, for Corex 240 NLG per tonne and for CCF 165 NLG per tonne.

Note that the production costs refer to the current situation. Energy prices will probably change in the future, resulting in changing cost-effectiveness of production technologies.

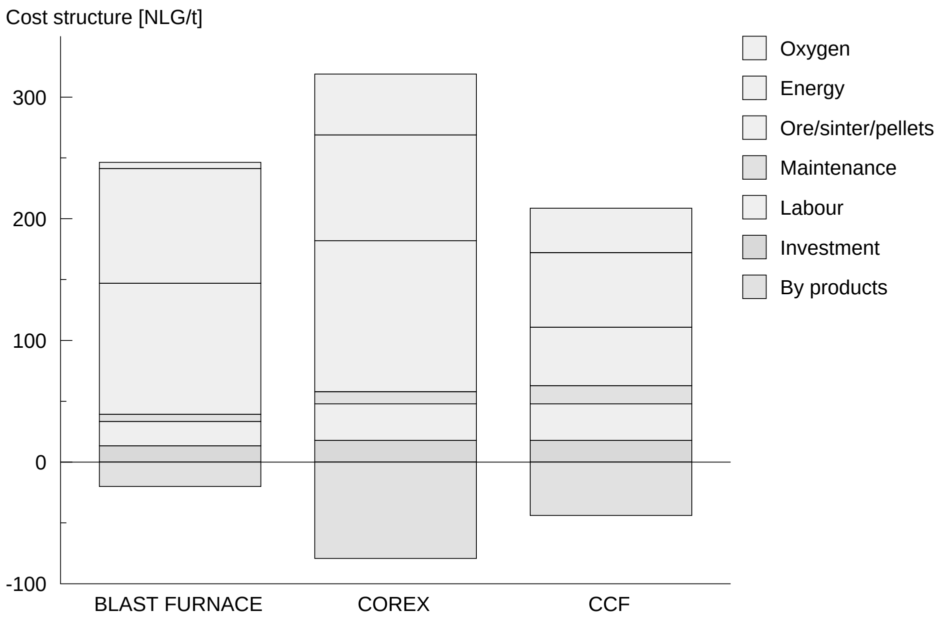

Figure 11.2 *Liquid iron production costs, the Netherlands*

Figure 11.3 shows the calculated steel production costs for the BOF, DRI/EAF and scrap/EAF route in the Netherlands. These steel costs refer to cast steel slabs, an intermediate product before the steel rolling. Comparison with the export prices (FOB) of steel slabs in Table 7.1 (367 NLG/t) shows a difference of 30-40 NLG per tonne. This difference can be accounted for by overhead and transportation costs.

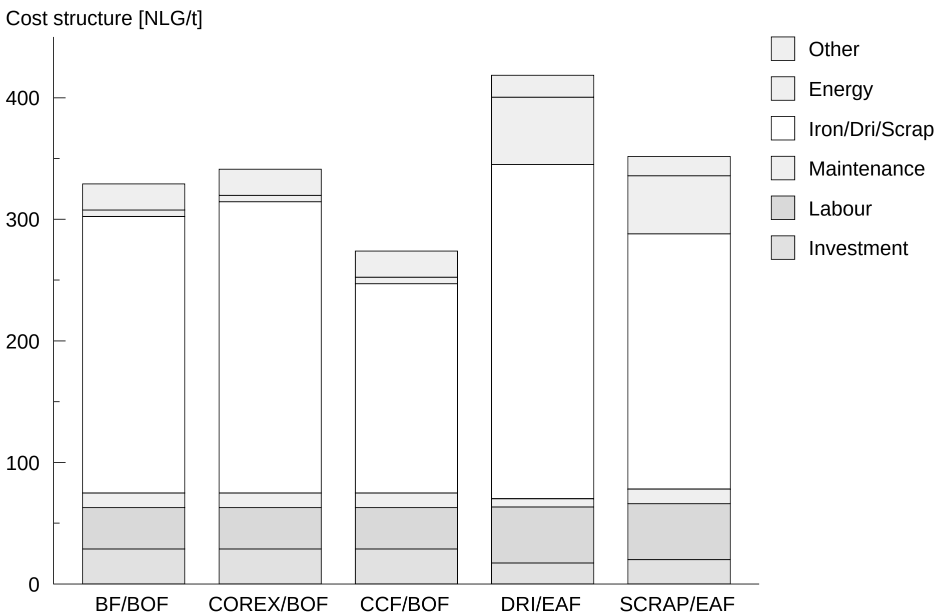

Figure 11.3 *Steel slab production costs, the Netherlands*

Figure 11.4 shows production costs for steel slabs in different countries with different production technologies. Transportation costs of these slabs to the Netherlands are separately indicated. The figure shows that the Dutch CCF is potentially the cheapest production option. Alternative processes show all similar or significantly higher costs than the Dutch blast furnace. This conclusion may however change if other processes can use iron ore fines instead of pellets.

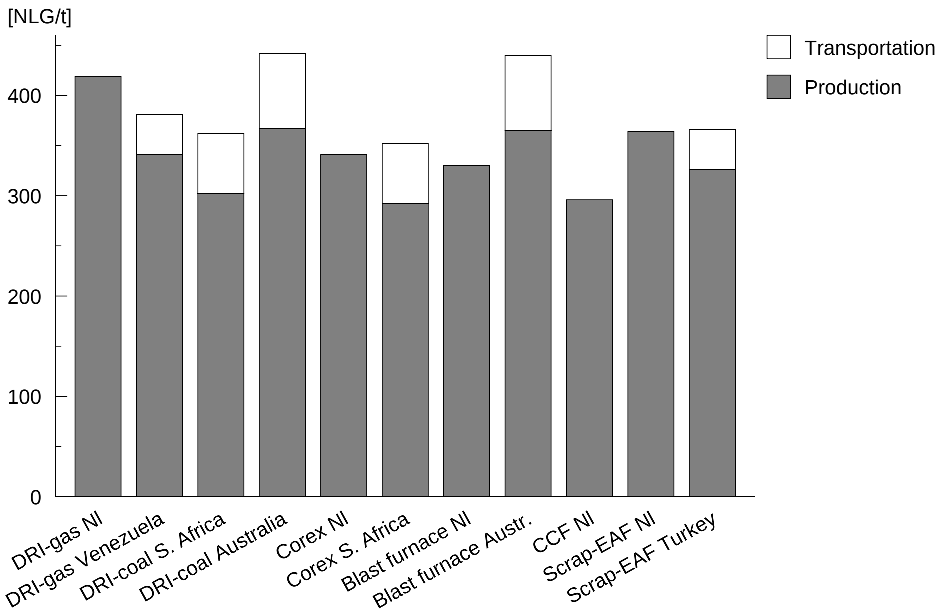

Figure 11.4 *Steel slab production costs, CIF Netherlands*

Figure 11.5 provides a comparison where the cheapest combinations of imports in the steel chain are compared: DRI imports from South Africa or steel slab imports from South Africa, compared to iron ore pellet imports and blast furnace steel production in the Netherlands. The results show that imports of DRI and subsequent steel production result in a similar price than for the Dutch blast furnace based steel production. Imports of steel slabs from foreign countries seem no feasible option: even the cheapest producer (South Africa, based on Corex iron) has higher production costs.

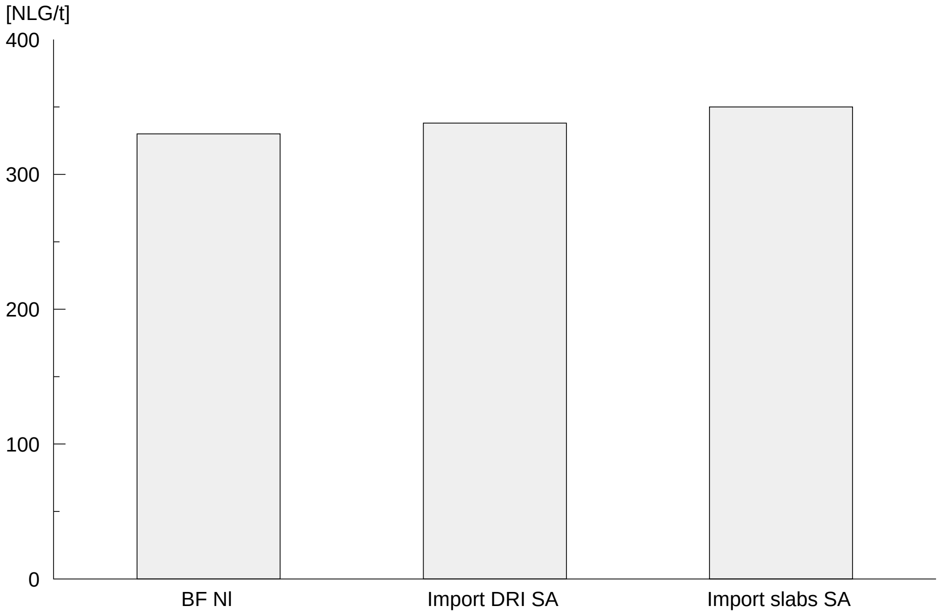

Figure 11.5 *Comparison of steel production options for the Dutch market with different imports*

Import levies must be added to these cost prices for foreign producers. Levies for imports from outside the EU (South-Africa, Australia figures) and import levies into the US from the EU-15 countries are shown in Table 11.9. The levies for imports into Europe depend on the product category and range from 2 to 7%.

Table 11.9 *Import levies (% added to the import price)*

SITC code	Type	Import levy EU-15	Import levy USA[1]
720712100	Steel slabs/bars <0.25% C	2.2	3.4
720822980	Hot rolled coils	2.7	4.1
721012110	Tinplate	3.4	2.8
721331000	Steel wire <0.25% C	na	1.5
721632910	I-profiles	3.1	0.7
721933100	Stainless steel sheet	4.2	8.1
730410100	Oil & gas pipelines	7	6.4
730890990	Cast profiles	2.9	2.2

[1] Unpickled; excluding 0.19% customs fee (max. 400 US$) and 0.125% harbour maintenance fee.

11.3 Conclusions

The results in this chapter show that primary aluminium production is the cheapest at locations with low electricity prices and low labour costs. The Venezuelan case results in significantly lower production costs than the production in the Netherlands. The attractiveness of the Iceland case, with only low electricity costs, is not clear from this analysis. Considering the plans of Hoogovens to start a new smelter on Iceland, the electricity prices may be overestimated.

The steel industry in the Netherlands proves to be in a good competitive position. The higher significance of transportation costs for steel prevents large scale imports from countries with lower production costs. CCF in the Netherlands is on the long run the cheapest production option, if the current energy prices are used for the analysis.

The sensitivity of these conclusions for long term energy prices trends, cost assumptions and CO_2 policies is analysed in the next chapter.

12. SENSITIVITY ANALYSIS

The preceding chapters show the complexity of the iron and steel industry and the aluminium industry. Each assessment implies a number of assumptions that determine the outcome to a large extent. In order to provide some insight in the determining variables and the impact of certain assumptions, sensitivity analyses are presented for the calculations in Chapter 11. This is followed by a brief discussion how companies and the government can deal with future developments.

12.1 Cost/benefit sensitivity

In order to evaluate the sensitivity of different aluminium and steel production options, data from Chapter 11 for Dutch production costs are varied in order to show the sensibility of profitability for such variations. The energy prices are separately varied for all production sites that were considered in Chapter 11. The results for the Dutch primary aluminium smelter are shown in Figure 12.1. The input parameters for the cost analysis are varied - ceteris paribus - in a range where both ends represent extremes that could occur in the next two decades. The figure shows that the production costs are most sensitive for electricity prices (steepest slope). The range in alumina prices is however larger, resulting in higher cost price variations due to variations in the alumina cost price. This parameter is probably less dependent on national conditions, but rises or declines for all producers.

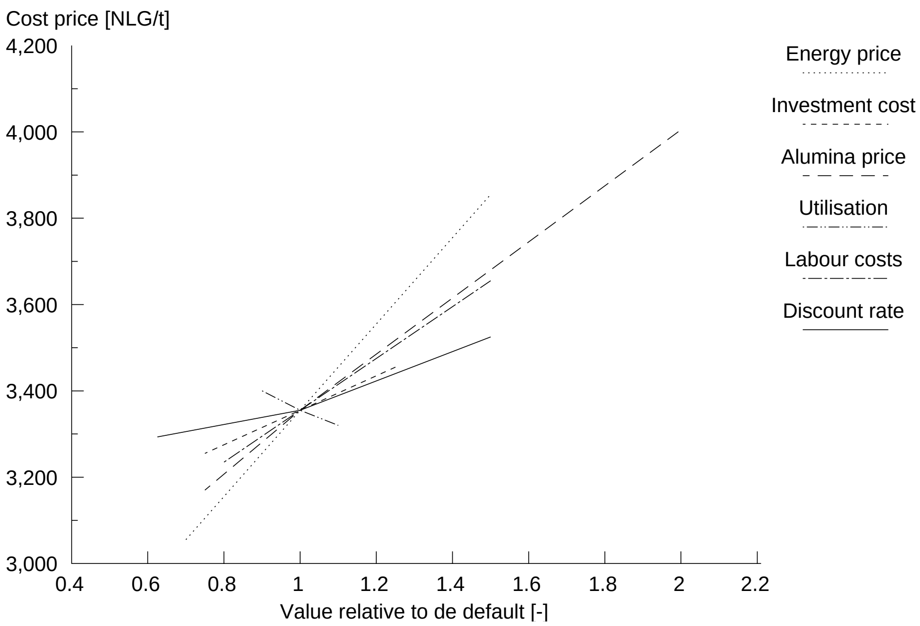

Figure 12.1 *Shift in production costs due to cost variations for primary aluminium production, the Netherlands*

Figure 12.2, 12.3 and 12.4 show the sensitivity of blast furnace, Corex and CCF in the Netherlands for key assumptions. Figures refer to the cost price of steel slabs (Figure 11.3).

The highest sensitivity (steepest slope) occurs for the labour costs for the blast furnace route. The highest variation in production costs (largest production cost difference) is however for all three production options related to the ore costs. The coal price is also in all three cases a second important variable, together with the utilisation rate. The value of the energy products (off-gases and steam) is important for the Corex plant, less important for CCF and least important for the blast furnace. If the ore price variation is excluded (because it is similar for all three processes), the cost price for blast furnace steel ranges between 310 and 350 guilders, for Corex between 310 and 365 guilders and for CCF between 270 and 315 guilders. These figures suggest that the choice between technologies is in the Netherlands in the current situation in favour of CCF.

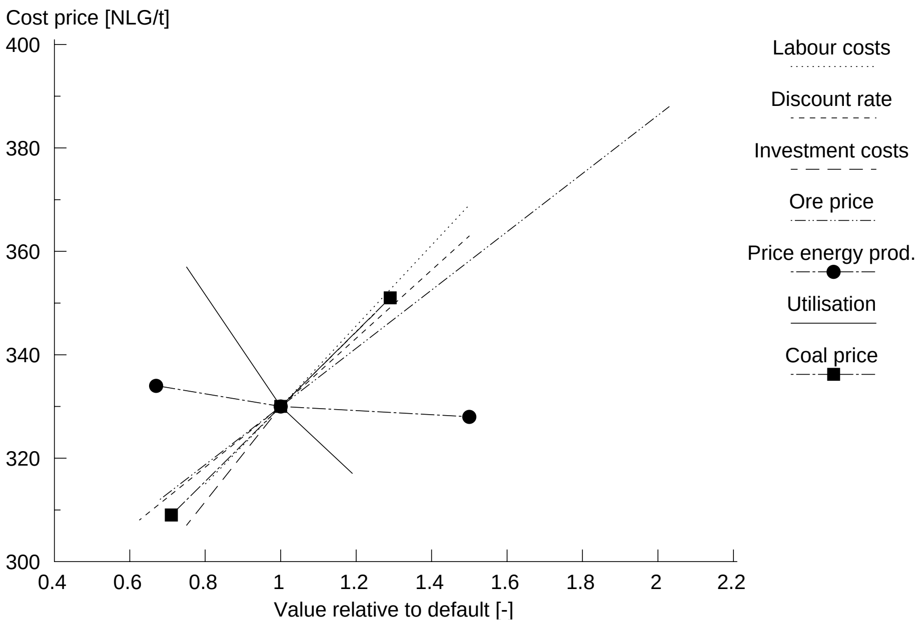

Figure 12.2 *Shift in production costs due to cost variations for blast furnace steel production, the Netherlands*

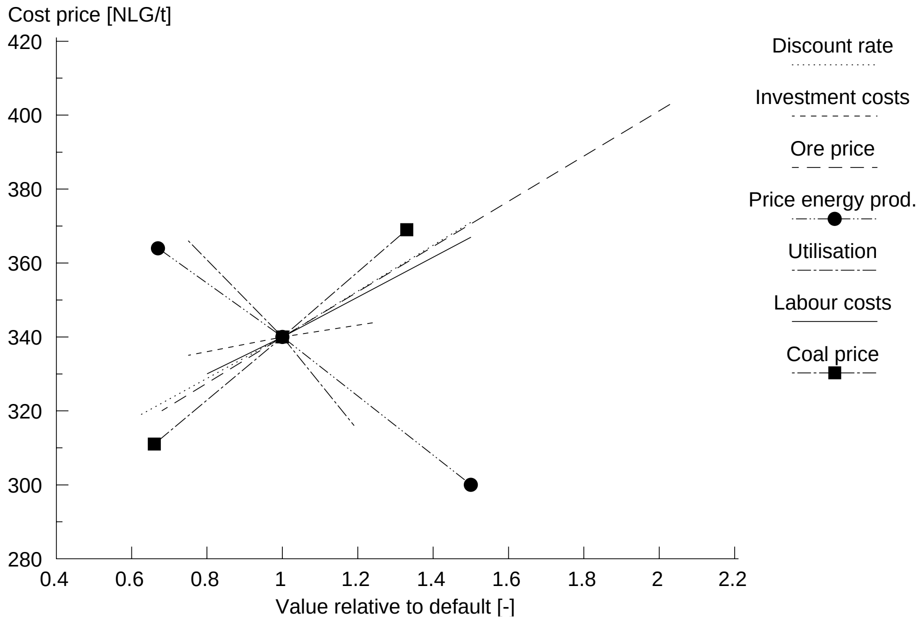

Figure 12.3 *Shift in production costs due to cost variations for Corex steel production, the Netherlands*

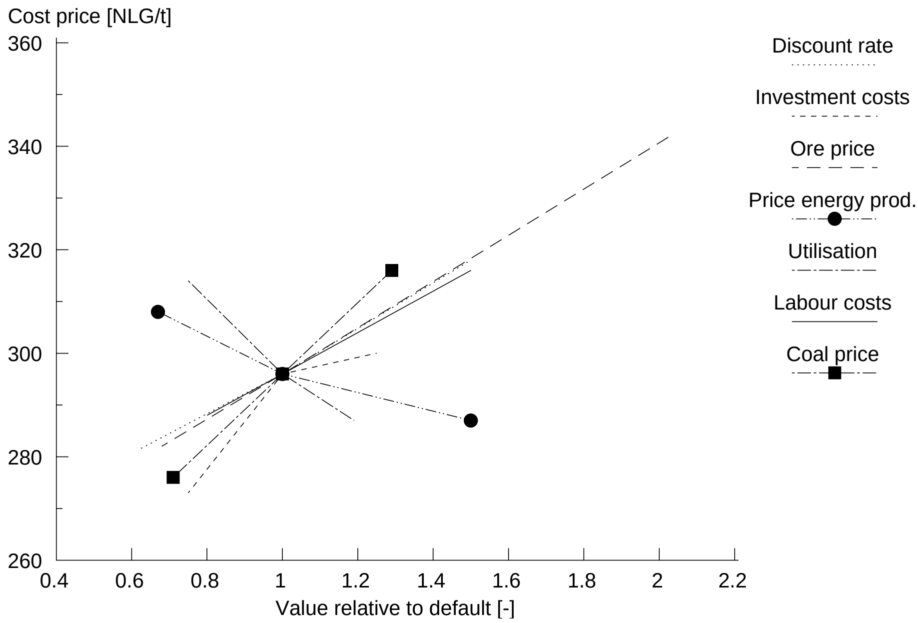

Figure 12.4 *Shift in production costs due to cost variations for CCF steel production, the Netherlands*

A key cost factor for both aluminum and steel production are energy prices and the value of energy by-products. The influence of energy prices on primary aluminium and steel production are shown in Figure 12.5. Energy costs are varied - ceteris paribus - in order to show the impact of energy price developments on the plant performance. Three points are shown, representing the current price, a low estimate and a high estimate. Current energy prices are low compared to energy prices in the last two decades, so the price range is much wider for higher prices than for lower prices.

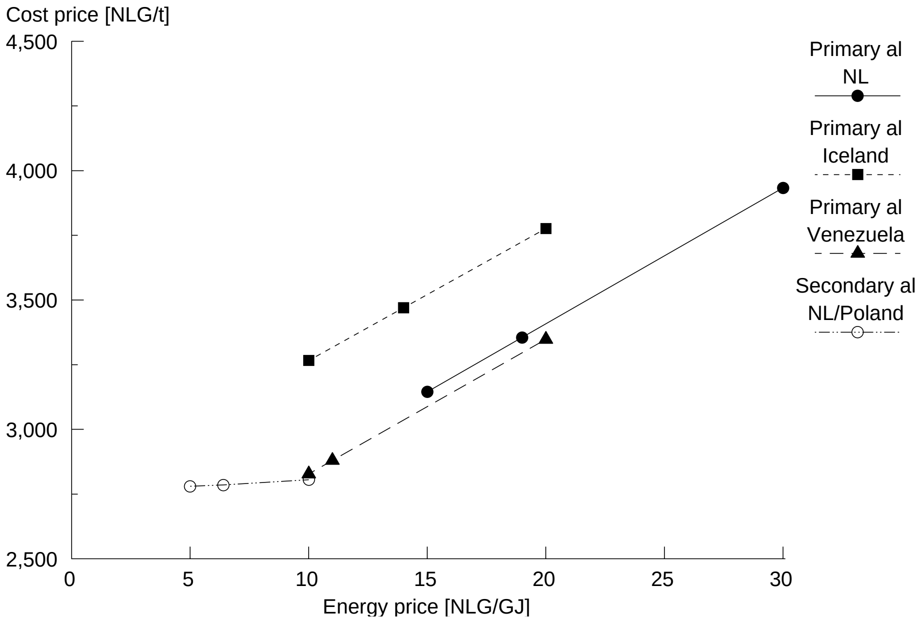

Figure 12.5 *Shift in production costs due to a shift in energy prices for different primary aluminium production options*

With regard to aluminium, Figure 12.5 shows the sensitivity of primary aluminium producers and the insensitivity of secondary aluminium producers for variations in energy prices. It is possible that low energy prices on one site coincide with high energy prices on another site, because electricity cannot be traded over large distances. As a consequence, regional changes in electricity markets can reverse the optimal choice for primary aluminium plant location. With regard to aluminium recycling, energy prices are irrelevant.

Figure 12.6 shows the sensitivity of steel production for energy costs. For Corex and CCF in the Netherlands, the value of the off-gases is varied, as the coal prices are considered to be more stable. For the other production options, the costs for the energy inputs is varied. The figures show that Dutch steel production is rather sensitive for energy prices. This sensitivity is related to future gas price policies.

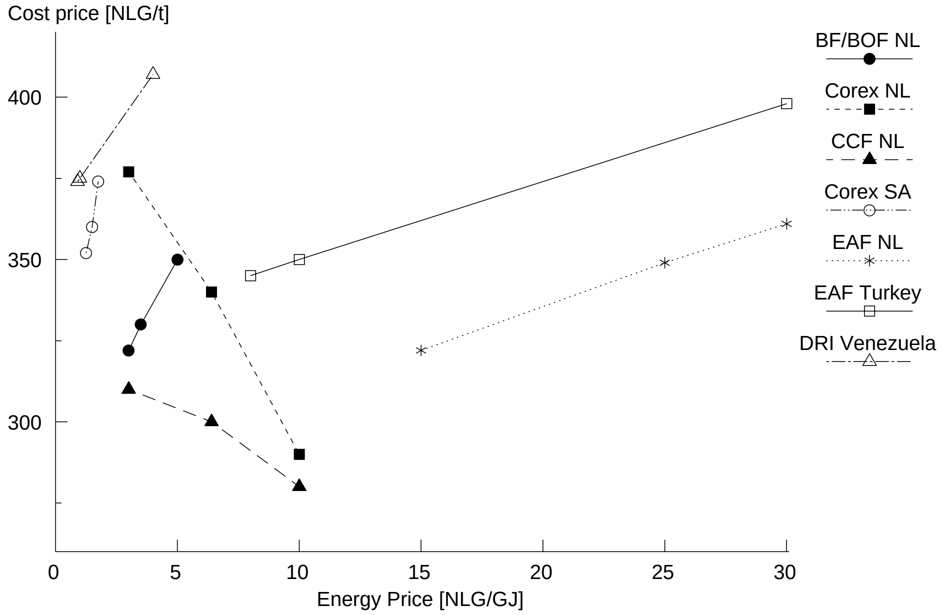

Figure 12.6 *Shift in production costs due to a shift in energy prices for different steel production options*

12.2 The impact of energy policies and CO_2 taxes on the aluminium and steel industries

Chapter 5 and Chapter 7 showed that energy costs constitute a major part of the production costs for both primary steel and primary aluminium production. As a consequence, changes in these prices can significantly affect the competitive position of the industry.

The impact of energy and CO_2 policies depends to a large extent on the scope of the CO_2 policies: a national, a European or a global range. The level of a tax (25%, 50% or 100%) plays also an important role. In the following assessment, the impact of an energy/CO_2 tax is shortly assessed. This is followed by a much more detailed assessment of the impact of a CO_2 tax on the Western European iron and steel industry.

National tax
With the introduction of a national tax, the cost price of steel and aluminium in the Netherlands will increase. The Dutch production becomes more costly than foreign production. This cost increase is paid by the producer and not by the consumer due to strong competition. If substantial, cost differences exist between Dutch producers and other producers, Dutch producers opt for a different production strategy. They continue production as long as possible and at minimum costs. As a consequence investments into new plants will end. The primary aluminium industry is more vulnerable for energy price increases than the primary steel industry (Compare Figure 5.6 and Figure 7.7). The aluminium industry will be significantly affected by energy taxes above 25%, the steel industry will be significantly affected at tax levels above 50%. Such policies imply that

investments will decrease and on the long term the production capacity in the Netherlands will decrease, too.

European tax
The European steel market can be considered as one market, with a quite uniform cost structure and European prices. A European tax will result in smaller effects than a national tax, but on a European scale. The European steel exports (see Figure 3.5) may however be significantly affected by such a tax. As a consequence, the steel industry is more vulnerable than for example the petrochemical industry [2].

The European aluminium industry operates within a global market. The introduction of a European tax will significantly affect the position of this industry, which is already in an unfavourable position due to high labour costs and high electricity prices. The imports from Russia, Canada and Latin America will probably increase.

Global tax
In case of a global energy tax, costs for the production of steel and aluminium will rise. Increased costs result in increasing prices that are paid by the consumer. The consumption of steel will be negatively affected in the transportation sector, but may increase in the building sector. The consumption of aluminium will increase on the long term due to its potential for fuel savings in the transportation sector [39].

The impact of a CO_2 tax may differ from the impact of an energy tax. Primary aluminium is produced on the basis of electricity, while steel production requires considerable amounts of CO_2-intensive coal. As a consequence, the steel industry may be considerably affected by CO_2 policies. Because of the large scope of abatement options and the comparatively high transportation costs, it is expected that the production technology mix within regions will be significantly affected, but the production quantity will be less affected.

The current aluminium production is already concentrated on locations with cheap and CO_2-free hydroelectricity. A global CO_2-tax will accelerate the relocation of smelters to such sites. In the European case, the relocation of aluminium smelters to Iceland poses an attractive option to use the substantial hydropower potential and to reduce global CO_2 emissions.

The MARKAL energy system model for Europe that is currently being developed at ECN has also been used for the analysis of the impact of CO_2 taxes on the steel industry. The current version of the model includes only the energy system and its improvement options. In the next version, the options in the materials system will also be included (e.g. increasing materials quality, substitution of materials, improved product design). The model can only be used for techno-economic assessment from a macro point of view. As a consequence, the optimal solution from a company point of view may significantly differ from the solution that is generated by MARKAL.

The model structure for the steel industry is shown in Figure 10.1. Three steel quality types are discerned: high, medium and low quality. The data in Table 6.4 show that different products require different steel qualities. Semi-finished products are divided into quality grades, with 20% high quality (sheet for cans, cladding, transportation equipment), 30% medium quality (tubes, sections) and 50% low quality (reinforcements, wire rod etc.). The quality mix changes in time in favour of the high quality.

Only one scrap quality is discerned in the model, which can be used to produce low quality steel. Trace elements can however be diluted by addition of DRI. This option allows production of medium quality steel from scrap. Four technologies compete for the high and medium market segment: the blast furnace with maximised coal injection, Corex, CCF and DRI/EAF. High quality steel can be downcycled to medium and low quality applications.

The calculation results for the base case without CO_2 reduction policies are shown in Figure 12.7 and Figure 12.8. The electric arc furnace steel production increases as the scrap availability increases. No major scale DRI production is initiated. The iron based steel production remains more or less at the same level. The results in Figure 12.8 show a quick change from the blast furnace technology to the Corex technology and also CCF technology. The dominance of Corex over CCF is caused by the assumption that large scale introduction of CCF can only take place from 2020 onwards, while Corex technology is already available in the year 2000. The residual blast furnace capacity is an input parameter (lower bound) for the model.

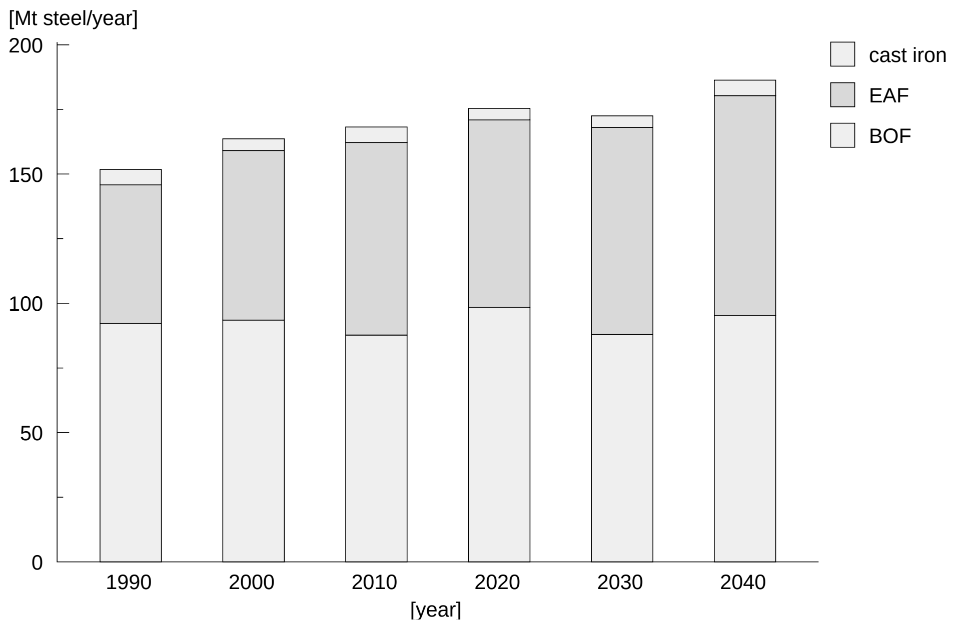

Figure 12.7 *Steel production in the case without CO_2 emission reduction policies, period 1990-2040*

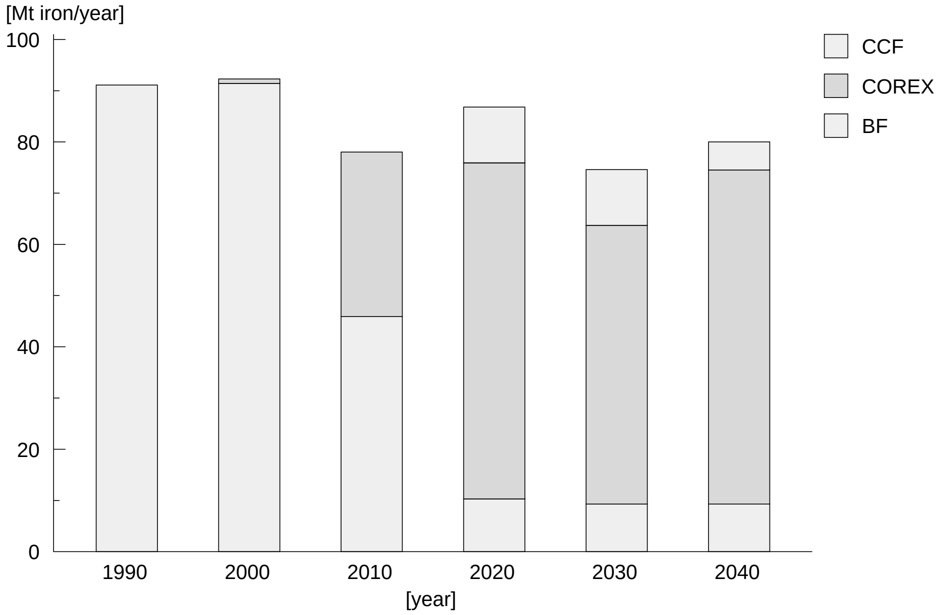

Figure 12.8 *Iron production in the case without CO_2 emission reduction policies, period 1990-2040*

Figure 12.7 shows a stabilising BOF steel production, while Figure 12.8 shows a decreasing iron production. The difference is accounted for by increased scrap use in BOF steel production.

The prominence of Corex in Figure 12.8 is remarkable, given the higher cost for Corex than for CCF in Figure 11.2. One reason is the current availability of Corex. The other reason are the energy price developments. The analysis in Chapter 11 was based on the current energy prices, while the analysis in this chapter is based on changing energy prices. The energy price scenario is shown in Figure 12.9. Because the gas price and the oil price rise much faster than the coal price, is becomes cost-effective to operate Corex as a coal gasifier with maximised gas production and iron as by-product.

In this analysis, it is assumed that Corex has higher amounts of by-products than CCF production (see Table 10.3 and 10.5): Corex production results in significant amounts of gas and steam by-product. Their value depends on the production costs for alternative energy sources. In many cases, natural gas is the competing energy source. It is assumed that the price gap between coal and natural gas increases from 2.5 NLG/t in 1990 to 5.3 NLG/t in 2050. If the price gap between coal and gas increases, the attractiveness of Corex increases, because coal gas can be sold at gas price. However, it may also be possible to use CCF technology to generate significant amounts of off-gases. This would result in an increasing competitiveness of CCF compared to Corex technology.

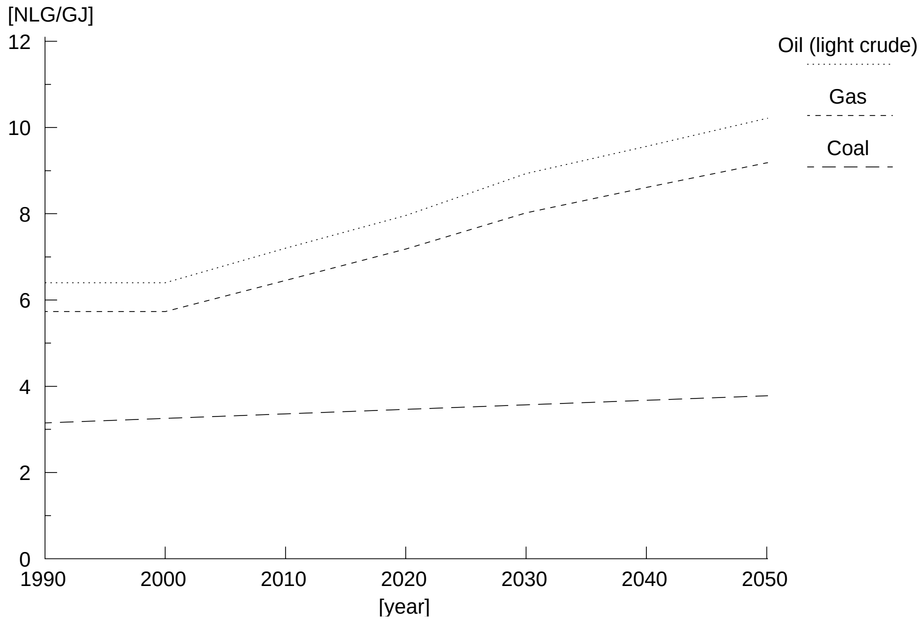

Figure 12.9 *Energy price scenario*

One should keep in mind that gas production is currently not considered as a core activity by steel producers. It remains to see if high gas prices pose sufficient incentive to change this attitude.

A second point that may influence the choice for Corex or CCF is the ore quality. Corex has been specifically designed to cope with very low quality iron ores. It is not clear if CCF can also be used to process low quality ores. Significant amounts of slag materials may pose problems in the cyclone section. If CCF requires higher quality ores, this may on the longer run result in a cost disadvantage in the order of 20 NLG per tonne iron: pellet feed trades currently at a price of 80-85% of the price of ore fines (per Fe 1%/dmt FOB, see also Figure 7.5 and 7.6). This potential disadvantage of CCF was not taken into account in the analysis.

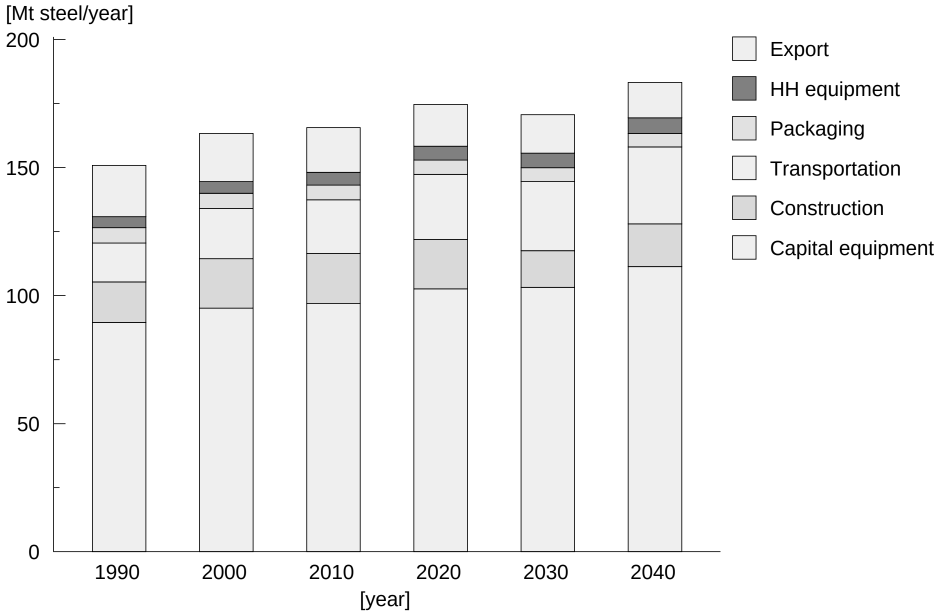

Figure 12.10 *Development of steel demand, base case, 1990-2040*

In order to study the impact of CO_2 reduction policies, three emission penalty paths have been studied. The penalties start in 2010, reach their ultimate level in 2020, and stabilise afterwards. The ultimate levels are 50 ECU/t CO_2, 100 ECU/t CO_2, and 200 ECU/t CO_2. These are shown in Figure 12.11.

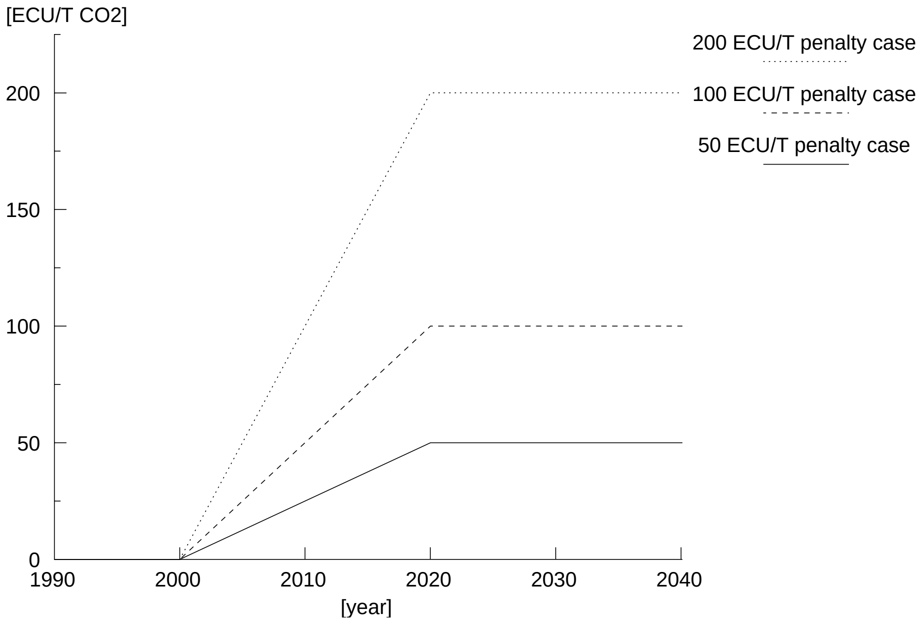

Figure 12.11 *CO_2 emission penalty cases*

Two sets of emission reduction scenarios have been studied. In one set, the possibility of CO_2 removal and storage is considered. In the other set, this option is not considered.

The results regarding iron production for the year 2020 for both sets of calculations are shown in Figures 12.12 and 12.13. In the case without CO_2 storage, The iron production declines as the DRI-EAF route substitutes the iron-BOF route. The remaining iron production shows an increasing fraction of CCF, the technology with the lowest coal consumption. In the case where CO_2 removal is introduced, the iron production is hardly affected by CO_2 penalties. The fraction of CCF increases initially at the level of 50-100 ECU/t CO_2, but declines again in favour of Corex at the emission penalty level of 200 ECU/t CO_2. At this penalty level, CO_2 storage is introduced for Corex. Corex can be used to deliver both CO_2-free iron and CO_2-free electricity (note: no CO_2 removal has been modeled for the other electricity production technologies).

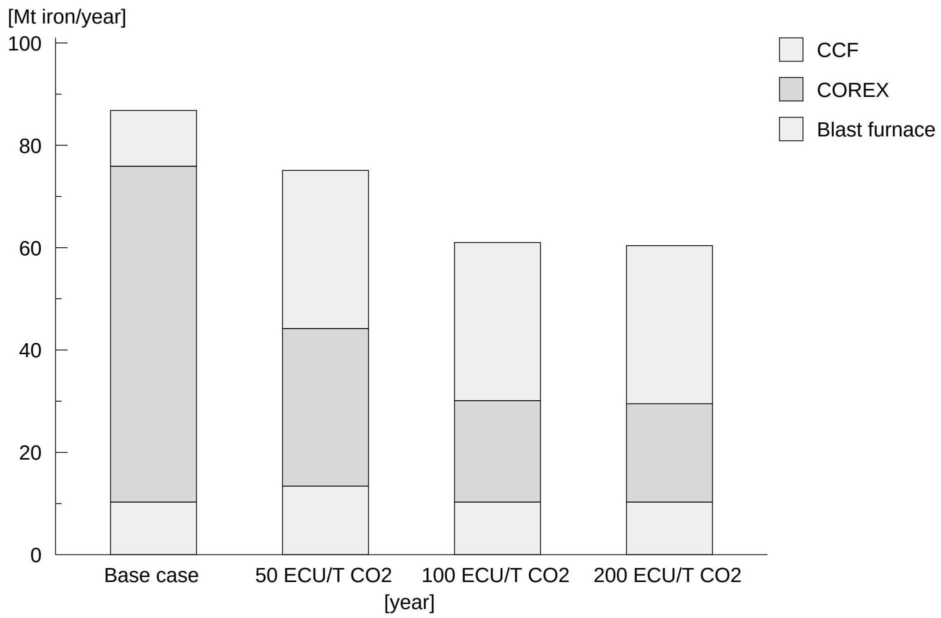

Figure 12.12 *Iron production in 2020 with increasing CO_2 penalties, case without CO_2 storage*

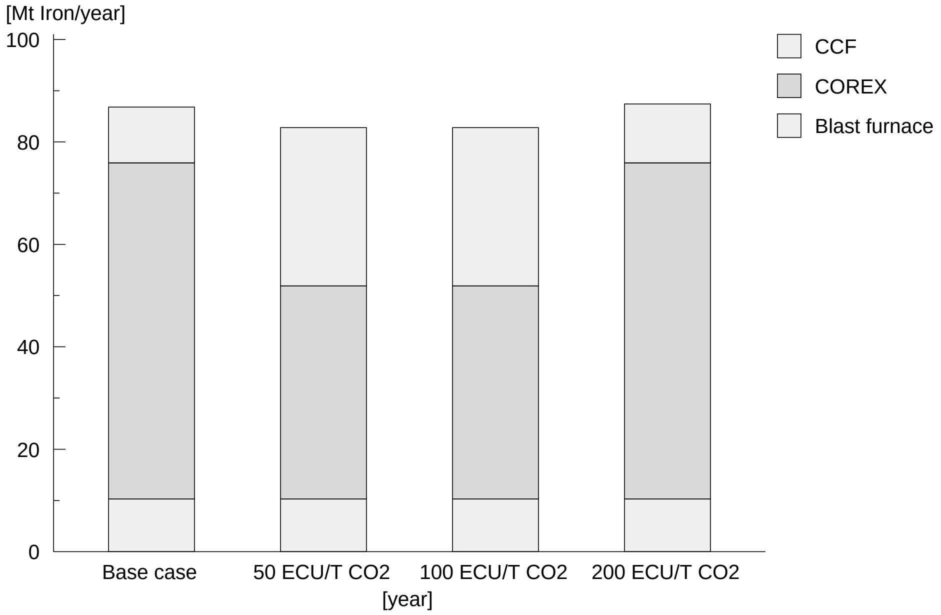

Figure 12.13 *Iron production in 2020 with increasing CO_2 penalties, case with CO_2 storage*

The technology mix in the case with CO_2 storage depends also on the removal and storage costs. In the calculations it was assumed that these costs are in the range of 30-40 ECU/t. If these costs are raised to the level of 50-60 ECU/t, the production technology changes to DRI/EAF (Figure 12.14).

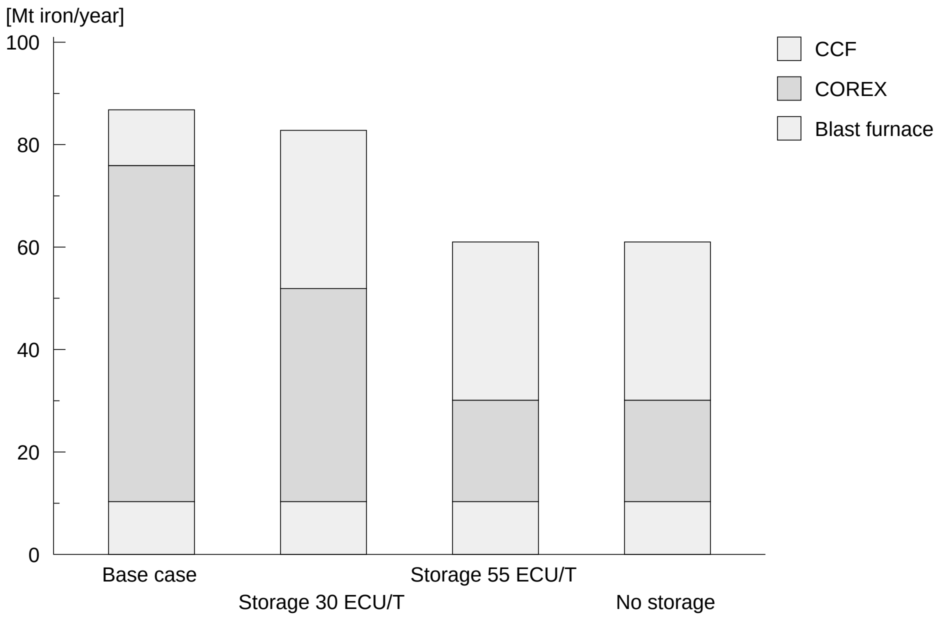

Figure 12.14 *Iron production in 2020 base case (no penalty) and penalty cases 100 ECU/t CO_2, varying assumptions for removal and storage*

The demand for steel is hardly affected by the emission reduction penalties. Figure 12.15 shows the impact of a 100 ECU/t CO_2 penalty on the relative materials prices. The figure shows that the competitiveness of steel increases compared to concrete, but decreases compared to polyolefins and paper. The position compared to aluminium is hardly affected. This comparison does however not yet include any savings during the product use phase and the recycling phase. It is however safe to say that the competitiveness of steel will improve in the building and construction sector (compared to concrete), while it will decrease in the packaging sector (compared to polyolefins and paper).

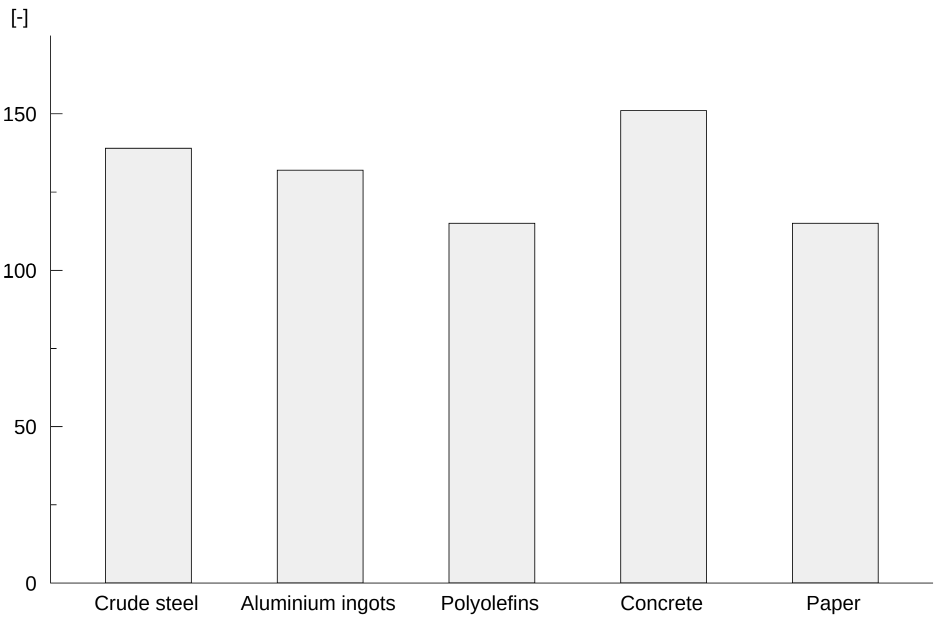

Figure 12.15 *Relative materials prices in 2020, case with CO_2 storage (base case =100)*

The choice of a different production technology mix has significant consequences for the energy consumption of the iron and steel industry. The energy consumption in 2020 ranges from 2.4 (high penalty, no CO_2 storage) to 3.2 EJ (no penalty).

As a consequence of the CO_2 reduction policies, the steel market splits into three distinctive segments. Figure 12.16 shows the shadow prices for the three steel qualities in the base case and the reduction cases (without CO_2 storage). It is clear that the high quality materials suffers most from CO_2 penalties, while the scrap based EAF production remains relatively unaffected because of its low CO_2 emissions. This assumes off course that scrap prices are not affected by CO_2 policies. Given the global character of the scrap trade, foreign EAF steel producers will probably try to buy more scrap in order to substitute their own primary steel production. This will result in an upward trend for scrap prices.

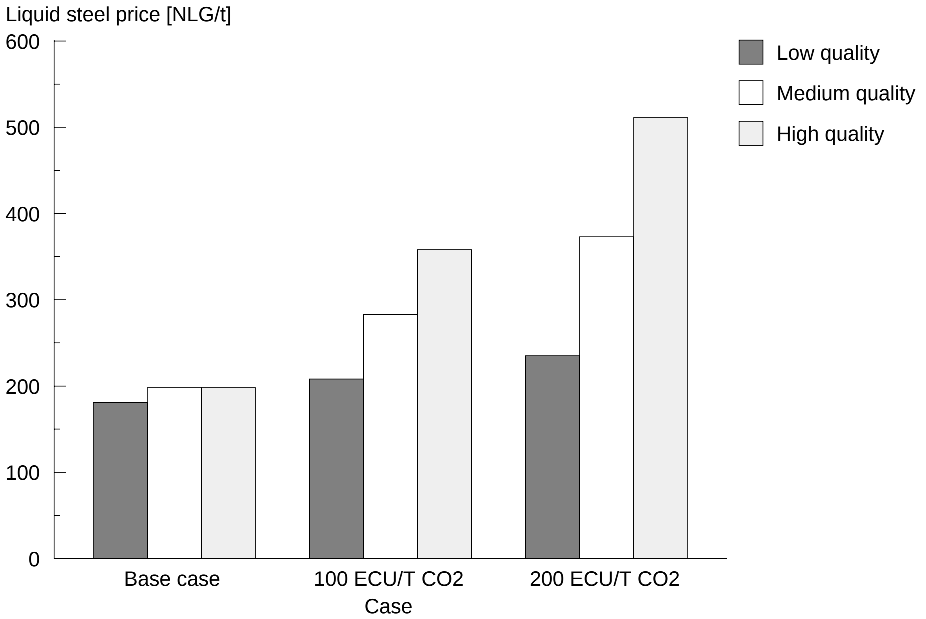

Figure 12.16 *Shadow prices for different steel qualities in the cases with and without CO_2 penalties*

12.3 Comparison with other studies

The IEA world energy outlook provided in 1996 a detailed analysis of the medium term (until 2010) outlook for the global iron and steel industry [140]. One of the regions in their study is the OECD. Some key assumptions in their analysis are shown in Table 12.1. The IEA study is based on econometric analysis, a different approach than the technology/physical materials flow approach in this study. Two scenarios are analysed, called the capacity constraints and the energy savings scenario.

Table 12.1 *Key assumptions in the IEA scenario study with regard to the OECD iron and steel industry*

	1993	2010
Capacity constraints case		
Share BOF [%]	65	57
Share EAF [%]	35	43
Production (relative to 1993)	100	114-116
Efficiency (relative to 1993)		
BOF	100	84-90
EAF	100	95-98
Steel intensity of GDP (relative to 1993)	100	80-86

In some respect, the data in this report are in line with the IEA forecast. Because Western Europe is not separately considered by the IEA, a straightforward comparison is not possible. The increasing fraction of EAF production is in accordance with the forecast in this report. The IEA does however not consider the development of smelting reduction technologies. The growth of production seems high (1% per year), but may be accounted for by the Asian OECD members (Japan and South Korea).

The efficiency increase for BOF seems feasible for the average OECD steel plant (note that this figure includes both energy efficiency increases and increasing energy intensity due to changing product mix). Because Hoogovens is already fairly energy efficient, and the company has still a significant potential to switch to products with higher added value, the efficiency increase is lower than for the European average plant.

A second interesting study by Edström and von Scheele [141] compared different iron production technologies with regard to their costs. The cost structures from this study and the calculated cost structures for the Netherlands from Figure 11.2 are compared in Figure 12.17.

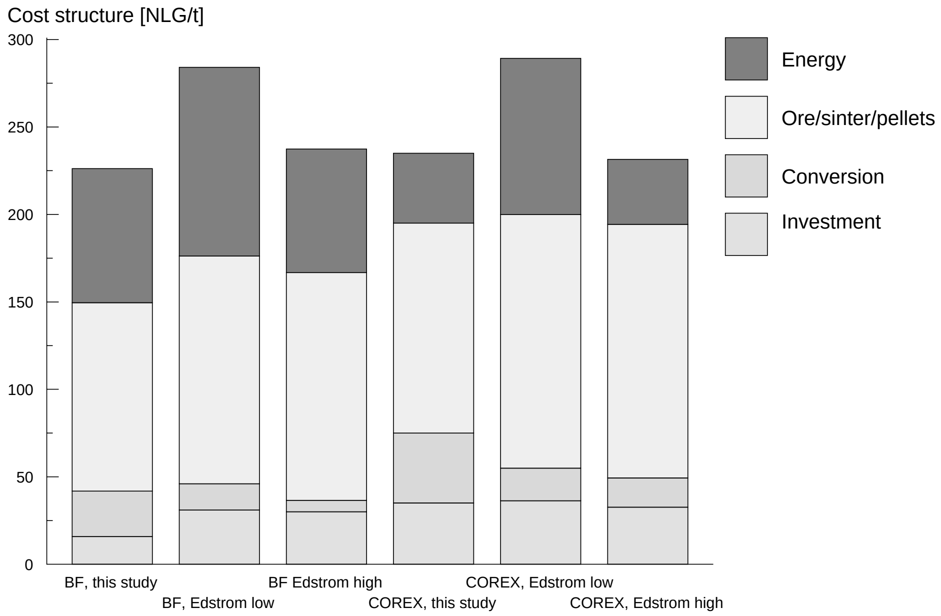

Figure 12.17 *Comparison of cost structures for iron production, this study and (Edström and von Scheele, [141])*

The data for Edströms blast furnace refer to a balanced oxygen blast furnace, a furnace with high coal injection rates (370 t/t liquid iron vs. 230 t/t in this study) and high oxygen consumption rates (0.35 t/t liquid iron vs. 0.1 t/t liquid iron in this study). Because of the high oxygen consumption, the hot stoves for air preheating can be avoided and the top gas has a higher heating value (5-6 MJ/Nm^3 vs. 3-4 MJ/Nm^3 for a conventional blast furnace). This would allow the use of BF gas for heating purposes. The value of the top gas is a variable: 4.7 guilders per GJ in the low case, 9.3 guilders per GJ in the high case (6.4 guilders per GJ in this study). Given these differences, the data in Figure 12.17 seem more or less in line. The data in this study suggest somewhat lower production costs than Edström. The cost difference is partially accounted for by lower estimates for investment costs in this study. However, these lower estimates are balanced by higher estimates for conversion costs (labour, maintenance).

Edström provides similar data for the Corex process. These data are also shown in Figure 12.17. The data from both studies seem again in accordance. Again, this study suggests somewhat lower production costs. The conclusion for the short term in the Edström study is the same as in this report: Corex technology will not yet replace blast furnaces on a large scale. The situation may however change in the future. Corex offers larger technological improvement potentials than the blast furnace. Future economies of scale, rising coking coal prices, decreasing oxygen prices, the potential to use low quality coal and iron ore, reduced environmental impacts and the potential to produce large amounts of gas by-products with a flexible production capacity are considerations in favour of Corex. Increased CO_2 emissions are the main disadvantage of this new technology. Hoogovens' CCF technology is basically in a similar position with similar advantages and disadvantages, but this technology is not yet proven on a commercial scale. The use of ore fines results potentially in lower production costs than for Corex iron.

In the case of CO_2 emission reduction, buying DRI from foreign countries or the own production of DRI may become attractive. It will probably also result in increased scrap recycling rates, the potentials for increased recycling are however limited.

12.4 Conclusions

Energy prices play an important role in the production costs of both primary aluminium and steel. The sensitivity is the highest for primary aluminium, with its large fraction of electricity costs (which are currently everywhere well below the average market price).

The future Western European energy consumption in the iron and steel industry will be significantly affected by the production technology mix, which is again dominated by the CO_2 emission reduction policies. Their lower inherent production costs (especially for CCF) suggest a shift towards smelting reduction.The impact of higher energy prices (oil and gas prices) will be beneficial for the smelting reduction processes with the highest amounts of energy by-products. As a consequence, CCF should also be tested for the potential to operate in such a mode. MARKAL results show a large scale introduction of both corex and CCF. However, these results should be nuanced in absolute terms; there is still much uncertainty regarding process parameters, product qualities, technological feasibility of new process routes and the costs of new process routes.

CO_2 emission mitigation can reduce the attractiveness of smelting reduction. In case cheap large-scale CO_2 removal and storage technology is developed, CO_2 emissions can be reduced by end-of-pipe measures. However, if the removal and storage costs increase to levels above 100 NLG per tonne CO_2, it becomes more attractive to switch to DRI/EAF based steel production. This option is also introduced in case CO_2 storage is not developed, a situation that may occur due to unforeseen technological problems or due to public opposition.

A final caveat regarding the analysis in this chapter is that MARKAL provides only insight in the macro-economic optimisation. The optimal solution may differ from a company point of view due to a different optimisation strategy, like different investment criteria, existing capital equipment, plant configurations etcetera.

13. PRODUCTION AND ENERGY CONSUMPTION FORECAST 1995-2020

The goal of this chapter is to forecast energy demand developments for Dutch steel and aluminium production. The situation is different for steel and aluminium. For aluminium, a net import into Western Europe exists in a rapidly growing market, while for steel a decreasing European market is coupled to significant European exports. These different positions are important for the future developments in the Netherlands.

For aluminium, a European scope is sufficient for analysis of the demand side, while a global scope is required to analyze the supply side. The recycling market will probably remain in European hands, but the future of primary aluminium production is uncertain. This uncertainty depends to a large extent on the growth rate of aluminium consumption in Europe. This growth rate depends on the GDP growth rate and expanding aluminum use in existing and new products. The long term growth rate will not be analysed in detail: the extrapolation of historical trends in Chapter 3 is used.

For steel, a global demand analysis is required because a significant part of the European production is exported. On the supply side, foreign producers may become competitors for European producers.

The global primary aluminium production is dominated by a small number of companies, while steel production is based on a large number of national players. Steel is increasingly a custom made material, where quick response to market pull and the quality focus is a key to success. This market structure has significant consequences for the location of new production capacity, which must be able to deliver custom made material within short periods.

Given the national character of the European steel companies, it is unlikely that foreign European steel producers will locate a new steel plant in the Netherlands. Producers from other continents will have little inclination to force themselves upon a shrinking European market that is already characterised by overcapacity. Alternatively, it is unlikely that Hoogovens will move its steel production capacity abroad, because the cost advantage for the European market is negligible (see Chapter 11). As a consequence, the question to be answered is whether Hoogovens can compete with other European producers. With regard to the Nedstaal activities, a major expansion and upgrading of its current plant could result in a competitive bulk steel production. Such renovation seems however unlikely. Because of the low energy consumption compared to Hoogovens, the future of Nedstaal is of lesser importance for this study.

Aluminium is a material for which transportation costs are of minor importance. Few trade barriers exist and aluminium is sold in a limited number of alloy types. New capacity in the Netherlands seems unlikely because of the availability of cheaper electricity elsewhere. Aldel is an ageing primary aluminium smelter that is planned to be closed in 2005. Hoogovens is already looking for a foreign production site with low electricity prices. The decision whether Pechiney sustains its Vlissingen plant depends to a large extent on the future developments in the Dutch electricity market. This decision will be on the agenda somewhere between 2010 and 2015. With regard to the secondary aluminium production, there seems still no end in sight for the growth in production. The secondary production is however limited by the availability of aluminium scrap. Because of the much lower energy intensity of production, growth of the Dutch secondary production will have limited impact on the total energy consumption in the Netherlands.

The following sections will discuss:
13.1 European production volumes for steel and aluminium
13.2 Dutch production volumes for steel and aluminium
13.3 Energy intensity of production
13.4 Energy use forecast, based on the data from section 13.2 and 13.3

13.1 European production forecast

Figures 3.3 and 3.6 show the extrapolation of aluminium consumption and steel production, respectively. Based on the MARKAL calculations for the development of steel consumption in section 12.2, the demand for steel has been adjusted upwards. The model calculation is considered a better estimate than the extrapolation. It is thought that economic growth in the next two decades will be higher than the growth in the period 1975-1990 due to the ongoing European integration. This growth will result in increasing steel demand. The trend towards increased quality will slow down, because major materials efficiency improvements have been introduced in the last two decades. These presumptions are used to forecast future aluminium and steel market developments in Table 13.1.

Table 13.1 *Future aluminium and steel market forecast for Western Europe*

[Mt pa]	2000	2005	2010	2015	2020
Aluminium apparent consumption	7.8	8.5	9.1	9.6	10.0
Losses in production	pm	pm	pm	pm	pm
Aluminium scrap availability	4.2	4.8	5.7	6.4	6.7
Aluminium scrap recovery [%]	60	65	70	75	75
Aluminium secondary production	2.5	3.1	4.0	4.8	5.0
Net aluminium imports	1.0	1.5	2.0	2.0	2.0
Aluminium primary production	4.3	3.9	3.1	2.8	3.0
Steel apparent consumption	135	142	145	150	150
Net finished steel exports	20	18	18	16	15
Steel scrap based EAF	65	67	68	71	70
Steel primary production	90	93	95	95	95

While primary steel production remains at a constant level, Western European primary aluminium production is forecast to decrease in the next

25 years. The next question is if this will result in closures in the Netherlands or closures abroad. This issue will be addressed qualitatively in the next section.

13.2 Dutch production forecast

Aluminium

With regard to primary aluminium production, the Netherlands seem at first sight in a bad competitive position compared to countries like France, Iceland and Norway, because of the declining natural gas reserves and the expected closure of the Borssele nuclear power plant. If the position is compared to other European countries, the prospects seem however not so negative. Out of the 33 existing primary aluminium smelters in Western Europe, Pechiney Vlissingen is the 6th largest. As a consequence, the plant has some scale advantages: it is almost twice as large as the average Western European aluminium smelter. This may be an advantage in the struggle for the market share. Current plans are to close the Aldel smelter in 2005. A feasible scenario A1 seems closure of Aldel in 2005 and closure of Pechiney Vlissingen in 2015. Scenario A2 includes a complete refurbishing of Pechiney and a significant capacity expansion in order to achieve improved economies of scale. In scenario 2 it is assumed that Pechiney can sustain a low cost electricity supply because of heavy competition on the electricity market. The possibility of CO_2-free nuclear power imports from France result in a special position with regard to its electricity use, which is exempt from greenhouse gas reduction policies beyond 2010. Table 13.2 lists the production scenarios for Dutch primary aluminium production.

Table 13.2 *Production scenarios for primary aluminium in the Netherlands*

[kt pa]	2000	2005	2010	2015	2020
Scenario A1	250	200	170	0	0
Scenario A2	250	200	170	300	300

These scenarios represent a wider range than the scenarios for the aluminium industry that are used for the LT-97 study. These scenarios indicate for 2020 zero primary aluminium production as only closure of the Pechiney plant is considered [142].

Steel

The production of Hoogovens is determined by its production capacity for liquid steel. This capacity depends for the major part on the capacity for liquid iron and to a lesser extent on the scrap consumption. The liquid iron production depends on the blast furnace capacity. There is some potential for creep of the capacity of the existing blast furnaces (creep is a gradual increase of the production capacity of existing installations). The main options for increased production with existing production capacity are oxygen injection and plasma injection. These options are however costly and are not considered feasible strategies in a market with pending overcapacity.

Hoogovens operates currently 2 blast furnaces, no. 6 and 7. Blast furnace no. 7 was completely renovated in 1991 [143]. The volume was increased in order to ensure a capacity above 3 Mt liquid iron per year. Renovation will only occur after 12-15 years, between 2003 and 2006. Blast furnace 6 was completely renovated in 1986. Major reconstruction is due around the year 2000. No new processes that can replace the blast furnace capacity can be operational before 2006, unless a forced development trajectory can be successfully initiated. This would imply successfull development of a pilot plant before 2003 and subsequent investment in CCF technology. It seems unlikely that such rapid development will succeed.

As a consequence, renovation of both blast furnaces seems quite certain. This implies blast furnace based iron production at least until the year 2020. With regard to the production capacity, stabilisation or slight increase to 6.2 Mt per year (an increase of 20%) through enlargement of the existing blast furnaces during renovations seems possible, but is not considered in the scenarios because of the emergence of new steelmaking technologies.

A first likely scenario ‘CCF’ is renovation of the current blast furnaces (3 Mt capacity each) and slow expansion through addition of small smelting reduction plants (capacity 0.3-0.5 Mt each). Such an approach would ultimately allow more flexibility in steel production, because the smelting reduction production volume can be more easily adjusted. The shift from replacement of blast furnace capacity could start around 2015, when blast furnace 6 is again up for replacement. This will probably imply a higher production volume before 2015, when the smelting reduction capacity is gradually introduced, and a lower production after 2015, when the blast furnace is out of production.

The interesting question with regard to smelting reduction is which technology will be used, and how this capacity will be operated: maximised amounts of energy by-products or minimised amounts of energy by-products. The best strategy depends on the development of coal prices vs. gas prices and the future CO_2 policies in the Netherlands. Generally speaking, significant CO_2 reduction must be considered as a serious threat to steel production in Europe and especially for the Netherlands with its carbon intensive steel industry.

A second scenario ‘no CCF’ assumes that CCF development fails due to technological problems or due to harsh CO_2 policies. As a consequence, the DRI/EAF route is developed as a substitute. The steel production fluctuates much more in this scenario than in scenario one.

In scenario three, it is assumed that the steel market declines even further. Hoogovens cannot compete with the much larger remaining European steel producers due to lacking economies of scale. As a consequence, the company focuses on small volumes of high quality products with increased value added. With regard to the specific energy use, the shift towards higher quality products will result in increasing energy consumption. This trend is however more than off-set by the energy savings in the other process sections.

The decline in physical steel production does not imply an economic decline. If the product mix shifts towards higher quality products, the prices per tonne also increase: dematerialisation is an ongoing trend in Dutch steel production.

Table 13.3 *Production scenarios for Hoogovens in the Netherlands*

[kt pa]	2000	2005	2010	2015	2020
Scenario S1 'CCF'					
Iron from BF	5500	6000	5000	3000	0
Iron from CCF	0	200	1000	4000	8000
Hoogovens steel	6000	6500	6200	7700	8800
Hot rolling	4000	4500	5000	5000	5500
Cold rolling	2000	2500	2500	2500	3000
Scenario S2 'No CCF'					
Iron from BF	5500	6000	3000	3000	3000
DRI	0	200	1000	1500	2000
Hoogovens steel	6000	6600	4400	5500	6600
Hot rolling	4000	4500	5000	5000	5500
Cold rolling	2000	2500	2500	2500	3000
Scenario S3 'Quality imperative'					
Iron from BF	5500	6000	5000	3500	3500
Hoogovens steel	6000	6600	5500	3800	3800
Hot rolling	4000	4500	4000	3200	3200
Cold rolling	2000	2500	2500	2800	3000

These scenarios represent a wider range than the scenarios for the steel industry that are used for the LT-97 study. This study indicates for 2020 a primary steel production between 6 and 7 Mt. The scenarios in Table 13.3 are based on the expectation that the imminent revolution in the Western European steel industry will result in more significant changes in the production structure than in the last two decades [142].

13.3 Energy intensity of production

With regard to aluminium production, the average specific electricity consumption will decline when the Aldel smelter is closed. Pechiney is already a quite efficient smelter. It is assumed that the new smelter that is built after 2010 will result in a specific electricity consumption of 45 GJ/t Al. This implies that the inert anode and cathode technology development does not succeed. If these developments would prove to be successful, the electricity consumption after 2010 can decrease by 20%.

The energy intensity of production depends largely on the mix of technologies that will be applied and on the product mix that is characterised in Table 13.3. It is assumed that Hoogovens will develop its CCF technology into full scale in scenario S1. In scenario S2 it is assumed that extra CO_2 reductions are required, and Hoogovens will eventually switch to DRI in order to substitute the blast furnace technology. In scenario S3, no new technologies are introduced. Hoogovens can further optimize its blast furnace technology through increased fuel injection and oxygen addition. The competition from foreign primary steel producers results in decreasing prices for bulk steel. Quality of production becomes an imperative. Hoogovens specializes its production and focuses on the finishing operations. The energy intensive blast furnace iron production is reduced.

The energy use for steel rolling will probably decrease. If the hot connection is developed, the heat demand will significantly decrease. If the near net shape casting technology is further developed, the electricity demand for rolling will also significantly decrease. It is assumed that the latter technology is not applied at the Hoogovens site because of problems to achieve the desired materials quality. As a consequence, the energy intensity of cold rolling does not change in time.

13.4 Calculation of energy demand

The future energy consumption for primary aluminium production is analysed in Figure 13.1 and Figure 13.2. The secondary aluminium smelters and the anode production of Pechiney and Aluchemie are not included in these figures.

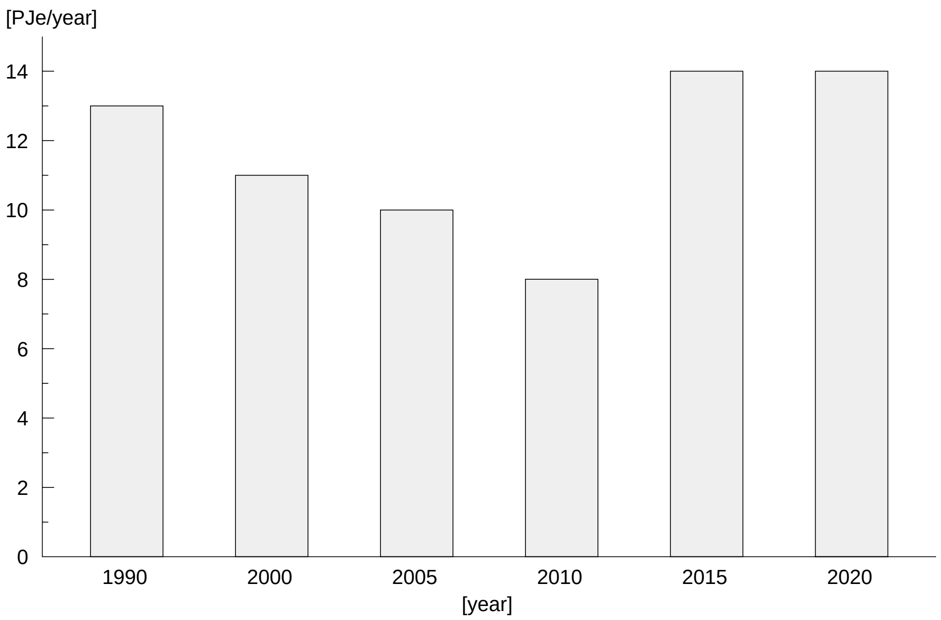

Figure 13.1 *Electricity demand for primary aluminium production for scenario A1, period 1990-2020*

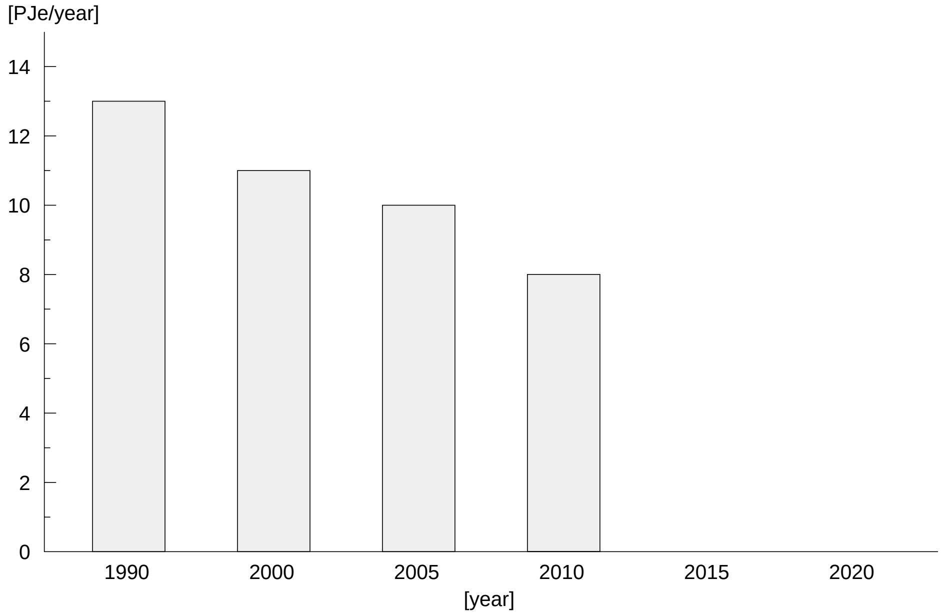

Figure 13.2 *Electricity demand for primary aluminium production for scenario A2, period 1990-2020*

Figures 13.3, 13.4 and 13.5 show the energy balance for Hoogovens IJmuiden for the three steel scenarios from Table 13.3. This balance includes the coke ovens. Both Nedstaal and ACZ de Carbonisation are not included in these figures. The oxygen production at Hoogovens is also not considered. The data for 1990 are data from the energy statistics and include the coke ovens.

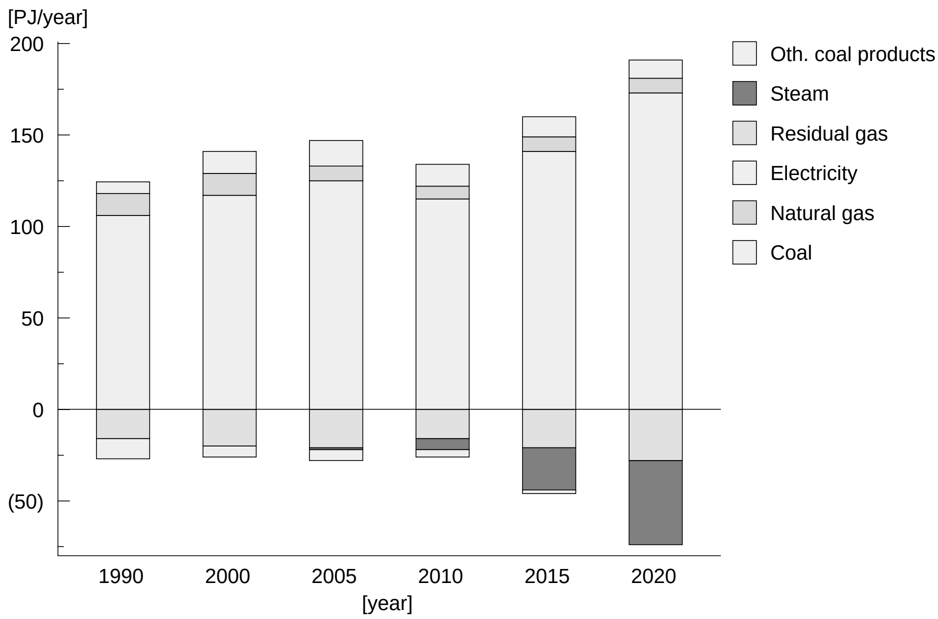

Figure 13.3 *Hoogovens energy balance for scenario S1 'CCF', period 1990-2020*

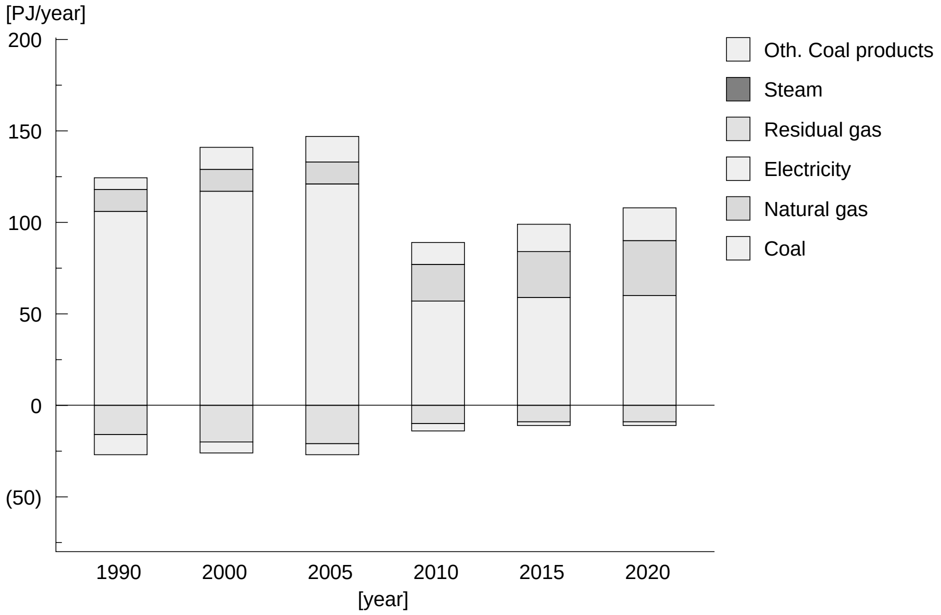

Figure 13.4 *Hoogovens energy balance for scenario S2 'no CCF', period 1990-2020*

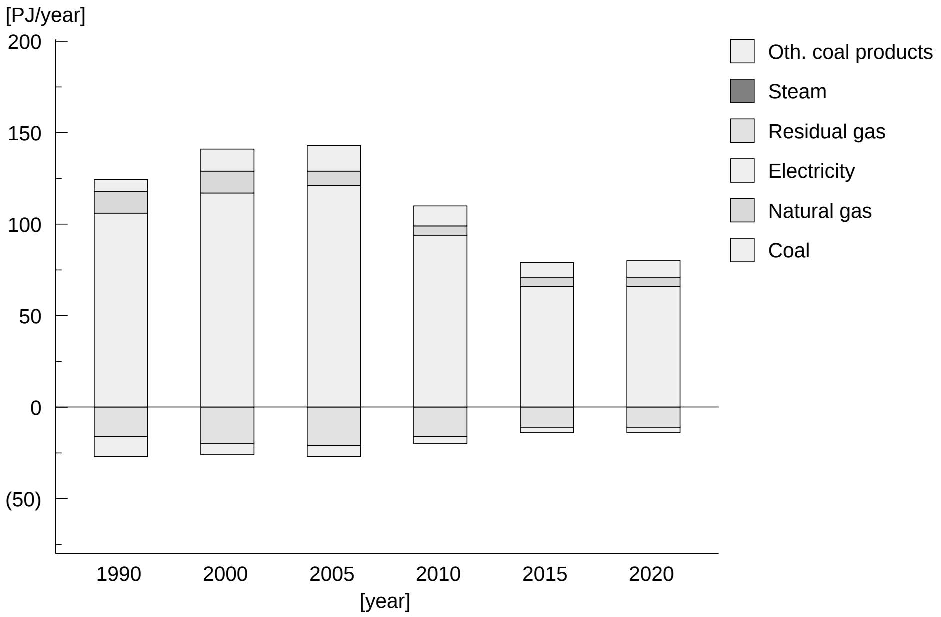

Figure 13.5 *Hoogovens energy balance for scenario S3 'quality imperative', period 1990-2020*

In conclusion, the future energy consumption of the basic metal industry is either stabilising or declining. Significant amounts of residual heat will become available in IJmuiden, which must be used for power production if no other application can be found.

14. CONCLUSIONS

Comparison of steel and aluminium shows clearly two metals in a different phase of their economic life cycle. They differ in their physical production volume, their technological progress and their importance for the economy.

Steel is produced by a large number of companies with a predominantly national character. Because of the stiff competition and readily available technology, the profit margin is small. Steel producers aim for vertical integration in order to alleviate price fluctuations and sales problems in bad years. Scrap based EAF producers can increase their market share as the post consumer scrap availability increases (Chapter 3).

Aluminium is still in the growth phase of the product cycle. Aluminium demand is still increasing, mainly due to substitution of other materials in the transportation sector and other light-weight applications (Chapter 3). Because of the increasing demand, there is little incentive to invest to the same extent as for steel in new technology and rapid product innovation (Chapter 4). Aluminium is globally produced by a limited number of large companies. The aluminium production is characterised by an oligopolistic structure with a global market (Chapter 9). The high product price (5-10 times the steel price) allows global aluminium trade. Aluminium recycling rates will probably further increase. Because large amounts of aluminium are stored in long life products, recycling can cover only a part of the aluminium market in the next two to three decades (Chapter 3).

Steel

History and present activities

Iron and steel production started in the Netherlands more than 75 years ago. One company, Hoogovens, represents currently 95% of the total steel production. The remaining 5% is produced by Nedstaal. Hoogovens uses the blast furnace technology to produce steel from ores. Nedstaal uses scrap based electric arc furnaces. Total steel production in the Netherlands has stabilised in the last 25 years (Chapter 2).

Hoogovens has recently expanded its capacity after the renovation of one of its two blast furnaces. The current blast furnace technology will be the basis for steel production in the next two decades. The increasing demand for high quality steel results in increasing energy use for rolling and finishing, but results also in an increasing added value (Chapter 6,7).

While scrap based steel production has rapidly increased throughout Europe, it has decreased in the Netherlands. Nedstaal cannot compete for bulk steel products and focuses on high quality market niches. The small scale of operations (reduced economies of scale) and the lacking investments in new installations are important reasons for Nedstaal’s low output. Nedstaal is nowadays focusing on wire products like springs and ball bearings and intends to shift away from own EAF steel production to the purchase of steel slabs and billets for further processing. As a consequence, its energy use will decline (Chapter 6,7).

Product market trends
The stabilising steel production in the Netherlands is related to the decreasing steel demand in all OECD countries. The growth of global steel demand is currently concentrated in Asia. Hoogovens exports significant amounts of steel to North America. The prospects for exports from the Netherlands to Asia seem less promising because of the significant transportation costs and the long delivery periods. Hoogovens’ location in IJmuiden where sea-going vessels can board proves to be a significant advantage, because transportation costs for both resources and products are low compared to producers at inland locations. Competition on the Western European steel market from producers that are located outside Europe seems less probable. Increasing quality requirements, increasing labour productivity, high transportation costs and still existing trade barriers make competition from other regions less likely. The exception may be DRI imports from outside Europe (Chapter 9,11).

European steel production is still higher than steel consumption because of significant net exports. This success makes European producers vulnerable to competition from abroad. If the export declines, serious restructuring of the European industry is required. Competitors within Europe face largely the same position as Dutch steel producers. Hoogovens seems in a good position to survive such restructuring because of the good location at sea, the high investments in process and product innovation and the ongoing vertical integration in the steel chain (Chapter 8,9).

Steel production faces strong competition from aluminum and plastics in a number of markets. In recent years, steel producers reacted to this competition with quality improvements. As a consequence of this quality improvement, the specific steel consumption for certain applications decreased significantly (dematerialisation). This decrease has not been not compensated by the increasing product consumption or by development of new steel applications. This dematerialisation trend is one of the reasons for the declining energy consumption within the steel sector. Both Hoogovens and Nedstaal are increasingly focusing on the high quality market segment. Hoogovens is currently heavily investing in increased quality and increased vertical integration with take-overs of foreign steel processors.

Current technology and energy efficiency
The current technology for steel making from ores is the blast furnace-BOF route. Hoogovens applies this technology. The company is a European leader with regard to energy efficiency. Coal injection rates are clearly above the European average, the recovery rate for residual gases is high, the blast furnaces have been recently completely refurbished. Coupled to a product mix that contains significant amounts of simple products like steel slabs, the specific energy consumption is low (Chapter 6).

The blast furnace technology is inherently more energy intensive than the scrap based steel production, because the chemical energy for ore reduction must be added. The blast furnace route at Hoogovens requires approximately 21 GJ per tonne cold rolled sheet, while Nedstaal's EAF production requires approximately 10 GJ per tonne steel wire. Because of the large fraction of blast furnace steel production, the total Dutch iron and steel industry is relatively energy intensive (Chapter 6).

Future technology and energy efficiency
The iron and steel industry is currently in a process of rapid technological development. The main goal is to substitute the expensive and environmentally problematic coke based blast furnace technology. On the short term, increased coal injection in blast furnaces and increased use of scrap based electric arc furnaces can relieve the coke production problem. On the longer term, the blast furnace iron production route will be replaced by processes based on direct coal use or by processes that are based on the use of natural gas. The coal based Corex process and gas based direct reduction are proven technologies that are currently applied abroad to produce iron from ores. Hoogovens opts for its own cyclone converter furnace (CCF) technology that could also replace the agglomeration step for the ore fines. This technology has however not yet been proven on a commercial scale. It remains to see if Hoogovens can find sufficient support for further development of this technology (Chapter 10,11,12).

An important benefit of these new technologies is more flexibility in production, because the scale of operations is almost an order of magnitude smaller than a conventional blast furnace, and because the production volume can be much easier adjusted. Such advantages are important in the volatile steel market. However, the small scale smelting reduction operations with significantly lower investment costs may open the market for new, small scale steel producers. Apart from the operational benefits, emissions like SO_2, NO_x and carbon monoxide will be significantly reduced by these new technologies (Chapter 10).

The best choice of technologies will depend on the future energy and CO_2 policies. Coal based Corex or CCF generate substantial amounts of energy by-products. Their competitiveness will increase if the natural gas price increases compared to the coal price, and no CO_2 taxes are raised. This type of operation depends however on the existence of markets for the energy products. Hoogovens' location in IJmuiden has no immediate links with chemical or other industrial complexes, so power generation seems the only feasible application for the residual energy (Chapter 12).

The combination of DRI and scrap allows the production of steel with very low CO_2 emissions. DRI can overcome scrap availability and scrap quality problems that currently limit global EAF steel production. However, calculations show that the DRI/EAF route is not competitive with the smelting reduction/BOF route in the situation without substantial CO_2 policies. If CO_2 can be removed and stored at costs below 100 NLG/t smelting reduction technologies remain the most attractive option for primary steel in the case of substantial CO_2 policies. DRI can become attractive if large scale CO_2 storage from smelting reduction processes is not applied. High removal and storage costs (>100 NLG/t) result also in a shift to DRI. In both situations, CCF will become an important technology.

However, one should keep in mind that the successful development of CCF is still uncertain (Chapter 12).

Substantial national and probably even European CO_2 policies will have a significant negative effect on the steel production activities of Hoogovens. Global policies will probably have little negative effect, but should be introduced gradually in order to allow timely adaption of investment plans.

On the short term, Hoogovens has no plans to switch to alternative technologies, because the two existing blast furnaces will last for at least 10 more years. Timely initiation of this transition can prevent operational problems related to new technologies. The announced introduction of thin slab casting and strip casting technologies will reduce the energy consumption in the rolling section while the production costs are simultaneously reduced.

Recycling and the scrap market
Scrap based EAF steel production is currently a cost-effective technology to produce steel, if modern technology is applied on a scale of 1 Mt annual production capacity or more. A second advantage with increasing importance are the reduced CO_2 emissions compared to the blast furnace steel technology. From both viewpoints, EAF technology seems attractive. However, the scrap availability is limited by quality constraints and scrap prices will rise with increasing demand. Rigid scrap selection and secondary metallurgy can probably prevent scrap quality problems, but will increase the production costs. Hoogovens, the main Dutch steel producer, has no EAF experience. Nedstaal has insufficient funds to upgrade its current facilities. However, the know-how regarding the upgrading exists and the incentives are apparent. In conclusion, increased scrap based EAF steel production seems less likely in the Netherlands.

Energy demand forecast
The energy demand forecast for the Dutch iron and steel industry depends on the future production of Hoogovens and the technology that will be applied. The appearance of a new primary steel producer seems less likely and is not considered. Three scenarios have been developed. The first scenario is an expansion of Hoogovens because of the successful CCF technology, which results in a significant competitive advantage. The coal consumption increases significantly, but the amount of energy by-products increases, too. The second scenario assumes a choice for DRI technology and scrap recycling initiated by policies for substantial CO_2 emission reduction. DRI allows flexible production of smaller batches with significantly lower CO_2 emissions. The energy consumption decreases and switches from coal to gas and electricity. In the third scenario, a switch to new smelting reduction technologies is not successful and Hoogovens retains blast furnace technology. Shrinking primary steel production in Europe makes Hoogovens focus on products with high added value with only one blast furnace. The result is a considerable decline in energy use, coal remains the dominant energy carrier (Chapter 13).

Aluminium

History and present activities
Aluminum production in the Netherlands can be divided into primary production from alumina and secondary production from scrap. Primary aluminium is produced by Pechiney and Aldel. Both plants started operation due to the availability of cheap electricity. The Pechiney operation in Vlissingen is closely connected to the nuclear power plant in Borssele. Aldel started after introduction of cheap gas for power production. The primary aluminium production stabilised in the last 25 years. The closure of primary aluminium production in the Netherlands has been forecast in the last decade. Closure plans are only known for the Aldel plant (in 2005), the future of Pechiney is still unclear. The decreasing global energy prices and the related low Dutch electricity prices are one important reason for the ongoing production in the Netherlands. The future role of the Dutch smelters depends ultimately not only on cost prices, but also on the company policies of Pechiney and Hoogovens (Chapter 2).

Aluminum recycling increased significantly in the last decade. The Dutch recycling companies seem currently in a better position than the primary aluminium producers. However, further expansion of recycling activities is limited by the availability of aluminium scrap.

Product market trends
The aluminium market is a global market. Foreign producers can enter the European market, the reverse seems highly improbable. Because the aluminium demand is still rapidly increasing, both within Europe and abroad, new aluminium capacity can be included in the market without long term price impacts. Aluminium is gradually gaining a position in the traditional steel markets. Its light weight, corrosion resistance, processing possibilities and easy recycling will strengthen its position on the long run.

Competing primary aluminium producers are primarily located in countries with low electricity prices. The availability of cheap hydropower in developing countries seems however not sufficient to initiate large investments in primary smelters. The stability of these favourable conditions on the long term is equally important. As electricity markets become more developed and liberated, both in developed and developing regions, extremely low or high electricity prices cannot last (Chapter 5,9).

Competitors from surrounding countries face similarly high or even higher electricity prices than Dutch producers. Many of these smelters are considerably smaller than the Pechiney smelter in Vlissingen, with less economies of scale. As a consequence, other European producers seem in a less advantageous position than Pechiney Vlissingen.

Technology and energy efficiency
The main energy use is related to the electrochemical conversion of alumina (Al_2O_3) to aluminium. The Hall-Héroult electrolysis process is a mature technology, but gradual improvements of both productivity and environmental performance are still possible (Chapter 4,10).

A new production technology for aluminium from bauxite seems currently not in sight. The only ongoing research in primary aluminium production is aimed at inert anodes and cathodes. Both options can significantly increase the energy efficiency. Introduction of inert anode technology can potentially reduce anode consumption and electricity consumption. The technological feasibility of such developments is however still unclear.

Improved technology can be applied in order to increase scrap recovery rates, especially with regard to aluminium in municipal solid waste (MSW). This will result in increased recycling. The impact of such developments on the energy demand of the Dutch aluminium industry is probably limited (Chapter 10).

National, European and even global CO_2 policies will significantly affect the Dutch aluminium production. Within the European framework, the relocation of smelting capacity to Iceland with its significant potential for hydropower poses an attractive option. On the shorter term, the CF_4 and C_2F_6 emissions from aluminium smelters can be significantly reduced by installation of alumina point feeders. This will reduce the greenhouse gas emissions considerably with 10-15 tonne CO_2-equivalents per tonne aluminium.

Energy demand forecast
The energy demand for aluminium production in the Netherlands will mainly depend on the future of Pechiney. The potential for increased energy efficiency is limited. If the operation in Vlissingen is prolonged, the electricity demand could even rise due to capacity expansion (Chapter 13).

APPENDIX A. PHYSICAL CHARACTERISTICS OF ALUMINIUM AND STEEL

Table A.1 *Aluminium alloy properties*

Al series	Main alloying element	Tensile strength [Mpa]	0.2% stretch limit [Mpa]	Corrosion resistance	Welding behaviour
1000	-	40-130	0-120	very good	very good
2000	copper	300-440	230-320	moderate	poor
3000	manganese	100-260	40-190	very good	very good
5000	magnesium	100-350	40-300	very good	very good
6000	magnesium/silicium	130-280	60-260	very good	good
7000	zinc	360-520	280-440	moderate	moderate

Applications

1000	lighting, electronics, chemicals, food, pharmaceuticals
2000	machines, transport, screws, forging and turning applications
3000	roofing, partitions, barrels, element door, furniture
5000	facades, windows, household appliances, ships, constructions, process installations, tanks
6000	decorative applications, transport, turning products
7000	machines, transport, high pressure applications

Table A.2 *Steel properties*

Steel type	DIN/Euro nrs.	Main alloying elements	Tensile strength [Mpa]	Flow limit [Mpa]	Elongation at break (L=5d) [%]
Construction steel	Fe310-690	-	290-900	175-365	8-26
Upgraded steel	C22-C60	-	540-980	290-570	11-22
Upgr. alloyed steel	CrMo/NiCrMo	Cr Mo Ni	690-1420	460-1030	9-14
Concrete reinf.st.	FeB220-500	-	220-500		
Stainless steel	XCrNi/XCrMo	Cr Ni Mo	740-1680	20-60	
Turning steel	S/SMn/SMnPb	S Mn	380-988	255-570	5-10

APPENDIX B. MODEL PARAMETERS FOR STEEL PROCESSES

The physical inputs and outputs of steel production processes and their financial equivalents are summarized in Table B.1. The category additives in Table B.1 includes fluxes, alloying materials and refractory materials.

Table B.1 *Energy and materials inputs and outputs per steel process [76,87]*

Process		Specific amount [units/t output]	Price [NLG/unit]	Cost [NLG/t output]
Coke oven				
Inputs				
- coking coal	[GJ/t]	43	3.5	150.5
Outputs				
- coke [t]		1.0		
- coke oven gas	[GJ/t]	5.1	6	30.6
- breeze, tar and oils	[GJ/t]	4.9	5	24.5
Sinter plant				
Inputs				
- iron ore		1.1	37	40.7
- limestone		0.1	25	2.5
- electricity		0.14	25	3.5
- coke breeze	[GJ/t]	1.7	3	5.1
Output				
- sinter	[t]	1.0		
Pellet plant				
Inputs				
- iron ore		1.2	37	44.4
- limestone		0.4	25	10.0
- gas		0.5	6	3.0
- electricity		0.14	25	3.5
Outputs				
- pellets	[t]	1.0		
Blast furnace				
Inputs				
- pellets	[t/t]	0.75	64	48.0
- sinter	[t/t]	0.70	64	44.8
- oxygen	[t/t]	0.10	50	5.0
- coke	[GJ/t]	8.7	7	60.9
- coal	[GJ/t]	6.5	3	19.5
Outputs				
- blast furnace gas	[GJ/t]	1.9	6	12.1
- blast furnace slag	[t/t]	0.25	28	7.0
- electricity	[GJ/t]	0.1	25	2.5
- liquid iron	[t/t]	1.0		
BOF				
Inputs				
- steel scrap	[t/t]	0.12	200	24.0
- liquid iron	[t/t]	0.95	pm	pm
- limestone	[t/t]	0.08	25	2.0
- oxygen	[t/t]	0.07	50	3.5
- additives	[t/t]	0.03		18.1
- electricity	[GJ/t]	0.1	25	2.5
Outputs				
- liquid steel	[t]	1.0		
- dust	[t/t]	0.1	0	0
EAF furnace				
Inputs				
- scrap	[t/t]	1.03	200	206.0
- limestone	[t/t]	0.01	25	0.3
- oxygen	[t/t]	0.1	50	5.0
- additives	[t/t]	0.02		15.9
- electrodes	[t/t]	0.01		22.5
- electricity	[GJ/t]	1.62	25	40.5
Outputs				
- dust	[t/t]	0.02	500	10.0
- liquid steel	[t]	1.0		

REFERENCES

[1] A.W.N. van Dril: Forthcoming.

[2] D.J. Gielen, D. Vos, A. van Dril: *The petrochemical industry and its energy use. Prospects for the Dutch energy intensive industry*. ECN-C-96-029. Petten, April 1996.

[3] COB/SER: *Energie en economie*. Sociaal-Economische Raad, the Hague, 1983.

[4] Krekel, v/d Woerd en Wouterse: *Energieheffing en concurrentiepositie*. Rotterdam, October 1991

[5] CBS: *Standaard Bedrijfsindeling (SBI 1993)*. Voorburg, 1992.

[6] CBS: *De Nederlandse Energie Huishouding, jaarcijfers 1993*, Voorburg/Heerlen 1994

[7] CBS: *De Nederlandse Energiehuishouding jaarcijfers 1994*. Deel 1. Voorburg, 1995.

[8] Organisation of European Aluminium Refiners and Remelters: *Secondary aluminium Europe Japan USA 94/95*. Düsseldorf, December 1995.

[9] European Aluminium Association: *European aluminium statistics 1990*. Düsseldorf, 1990.

[10] A. Braun, J. Isings: *Energieverbruik in de basismetaalindustrie*. Braun Consultants, Hengelo, June 1990.

[11] C. Peek: *IJzergieterijen*. SPIN, July 1995, RIVM/RIZA/DGM.

[12] CBS: *Produktiestatistieken voor de basismetaalindustrie*. Diverse jaren.

[13] Anonymous: *SIGE-lid Nedstaal*. SIGE berichten 13, no. 4, September 1994, pp. 11-12.

[14] D.G. Nijdam: *Keuzen in de technische geschiedenis van Hoogovens*. IJmuiden, September 1994.

[15] *'Batavieren' van Hoogovens maken opwachting*. NRC 1 March 1997, pp. 17.

[16] J.A. Annema, R. Albers: *Produktie van cokes*. SPIN, November 1992.

[17] J.J. Dankers, J. Verheul: *Hoogovens 1945-1993. Van staalbedrijf tot twee-metalenconcern*. SDU, The Hague, 1993.

[18] Eurostat: *Basisstatistieken van de gemeenschap*. 30st edition. Brussels, 1993.

[19] J. de Vries: *Hoogovens IJmuiden 1918-1968.* Ontstaan en groei van een basisindustrie. Koninklijke Nederlandsche Hoogovens en Staalfabrieken, 1968.

[20] P. Oberender, G. Rüter: *The Steel Industry: a Crisis of Adaption.* In: H. de Jong: The Structure of European Industry. Kluwer Academic Publishers, Dordrecht, 1993.

[21] Anonymous: *Reorganisatie Nedstaal kost 120 banen.* De Volkskrant, 14 May 1996.

[22] Anonymous: *Energiebesparing bij Hoogovens IJmuiden.* SIGE berichten, 1994.

[23] NOVEM: *Voortgangsrapportage ontwikkeling energie-efficiency Nederlandse ijzer- en staal-producerende indsutrie (NIJSI) 1989-1994.* 95/I168/EA/lh. Utrecht, 31 July 1995.

[24] Centraal Bureau voor de Statistiek: *Jaarstatistiek van de buitenlandse handel 1993.* Voorburg/Heerlen, 1995.

[25] H. Seebauer: *The aluminum industry in a Unified Europe.* Aluminium 69, no. 5, 1993, pp. 396-401.

[26] D. Dermer: *The European aluminium industry in today's industrial climate.* Aluminum vol. 69, no. 8, 1993, pp. 765-767.

[27] Anonymous: *The basic facts about the European aluminium market.* Aluminium 69, no. 11, 1993, pp. 956-961.

[28] C. Marchetti: *The future.* International Institute for Applied Systems Analysis, Laxenburg, May 1991.

[29] R. U. Ayres: *The Industry--Technology Life Cycle: An Integrating Meta-model?* International Institute for Applied Systems Analysis, Laxenburg, March 1987

[30] IISI: *Steel Statistical Yearbook 1994.* Brussels, 1995.

[31] IISI: *World steel in figures, 1995.* Brussels.

[32] Anonymous: *EU still needs to restructure.* Metal Bulletin, Monday 23 October 1995, pp. 54.

[33] OECD: *World steel trade 1983-1993.* Paris, 1995.

[34] K. Brown, M. Venie, R. Woods: *The increasing use of aluminium in automotive applications.* JOM July 1995, pp. 20-23.

[35] C.R. Fussler, B. Krummenacher: *Ecobalances: a key to better environmental material choice in automobile design.* Materials and design 12 (3), 1991, pp. 123-128.

[36] H.N. Han, J.P. Clark: *Lifetime costing of the body-in-white: steel vs. aluminium.* JOM May 1995, pp. 22-28.

[37] W. Bleck: *Anforderungen an Karrosseriewerkstoffe.* Stahl und Eisen 115, no. 4, pp. 55-63, 1995.

[38] IISI: *Competition between steel and aluminium for the passenger car.* Brussels, 1994.

[39] D.J. Gielen, P.A. Okken: *Optimisation of integrated energy and materials systems. Linked energy and materials flows; methodological considerations and model calculations for the Netherlands beyond 2000.* ECN-C-94-010. Petten, June 1994.

[40] S. Young, W. Vanderburg: *Applying environmental life-cycle analysis to materials.* JOM April 1994, pp. 22-27.

[41] D.M. Howell: *Metal cladding for roofs and walls - will it meet your needs ?* Construction & building materials vol. 2, no. 1, march 1988, pp. 10-15.

[42] Anonymous: *Cladding design data.* AJ focus July 1988.

[43] IISI: *Innovations in steel. Roofs and Façades around the world.* Brussels, 1995.

[44] Anonymous: *Cladding costs.* AJ Focus, July 1988, pp. 51-54.

[45] D.J. Gielen: *Buildings, Constructions and CO_2.* ECN, Petten, forthcoming.

[46] W. Hosford, J.L. Duncan: *The aluminium beverage can.* Scientific American, September 1994, pp. 34-39.

[47] F. v. Wees: *Recycling of beverage cans.* WEC Committee: The environmental and energy aspects of waste handling. Petten, September 1992.

[48] Anonymous: *Stalen drankenbus steeds lichter.* De Grijper 21 May 1993, pp. 3.

[49] Anonymous: *Intrec, specialist in aluminium recycling.* Aluminium, May 1989, pp. 15-18.

[50] I.K. Wernick: *Dematerialization and secondary materials recovery in the U.S.* JOM April 1994, pp. 39-42.

[51] D. Berry: *Recyclability and the selection of packaging materials.* JOM, vol. 44, no. 12, pp. 21-25, 1992.

[52] R. Steuteville: *The economics of aluminium recycling.* Biocycle January 1993, pp. 74-77.

[53] UN-ECE: *The evolution of the specific consumption of steel.* New York, 1984.

[54] C. Jonville, J. Thomas, C. Dreyer: *The influence of coke source on anode performance.* JOM August 1995, pp. 23-24.

[55] P. Atkins, H. Hittner, D. Willoughby: *Some energy and environmental impacts of aluminium usage.* In: Tester et. al. (eds.): Energy and the environment in the 21st century. MIT press (Ma), 1991.

[56] U. Mannweiler, F. Keller: *Design of a new anode technology for the aluminium industry.* JOM February 1994, pp. 15-21.

[57] K. Grjotheim, H. Kvande, Q. Zhuxian: *Key improvements to Hall-Héroult since the end of world war II.* JOM November 1994, pp. 32-35.

[58] K. Krone, J. Krüger, H. Orbon, H. Sommer, H. Vest: *ökologische Aspekte der Primär- und Sekundäraluminiumerzeugung in der Bundesrepublik Deutschland.* Metall 11, no. 6, 1990, pp. 559-568.

[59] Ch. Kamphuis: *Aluminium: Van bouw tot recycling.* In: Ketenbeheer aluminium, nu en in de toekomst. Workshop proceedings, 13 april 1994, Utrecht. NOH rep. no. 9438. Utrecht, August 1994.

[60] F. Bijlhouwer: *Recycling-technologie rond aluminium. In: Ketenbeheer aluminium, nu en in de toekomst.* Workshop proceedings 13 April 1994, Utrecht. NOH, Utrecht, 1994.

[61] R.D. Peterson: *Issues in the melting and reclamation of aluminium scrap.* JOM February 1995, pp. 27-29.

[62] International Iron and Steel Institute: *Aluminium, an industry profile.* Brussels, 1993.

[63] H.W. Lambe: *Plant cost vs. developing country location.* Chemtech February 1978, pp. 100-102.

[64] CBS: *Jaarstatistiek van de buitenlandse handel, 1989-1993.* Voorburg/Heerlen.

[65] *Today's News Headlines*, Tuesday 7 November 1995. Through Internet.

[66] H. Mulder: *EMS 52-Werkdocument metalen en verf.* IVEM, State University Groningen, March 1993.

[67] CBS: SBI 27+28+29. *Produktiestatistiek basismetaal-, metaalprodukten en machinebouwindustrie 1994.* Voorburg/Heerlen, 1996.

[68] Anonymous: *Aluminiumsmelter Aldel blijft tot 2005 nog open.* De Volkskrant, 10 February 1996.

[69] M. Beeldman, M. Menkveld: *Elektriciteitstarieven. Update model en inventarisatie alternatieve tariefstructuren.* ECN-I--96-012. Petten, March 1996.

[70] *Jaarstatistiek van de buitenlandse handel,* various years.

[71] Metal Bulletin, Monday 23 October 1995, pp. 61.

[72] IISI: *Recent trends in the seaborne transportation of iron and steelmaking raw materials.* Brussels, 1992.

[73] Fairplay, 2nd May 1996, pp. 49.

[74] Anonymous: *Freight rates indicators.* Containerisation International, June 1996, pp. 15.

[75] R. Konings: *Tarieven in het containervervoer.* Delftse Universitaire Pers, 1993.

[76] E. Worrell, J. de Beer, K. Blok: *Energy conservation in the iron and steel industry.* In: P.A. Pilavachi (ed.): Energy efficiency in process technology. Elsevier Applied Science, 1993.

[77] A.J.J.M. van den Elsen, T. Helleman: *Nedstaal-inventarisatie van energiesystemen en studie naar energiebesparingsopties.* Nedstaal, Alblasserdam, October 1995.

[78] World Energy Council: *Energy Efficiency Improvement Utilising High Technology. An Assessment of Energy Use in Industry and Buildings.* London, september 1995.

[79] J.B. Darby, R.M. Arons: *Energy and materials flows in the fabrication of iron and steel semifinished products.* Argonne National Laboratory. ANL/CNSV-8. August 1979.

[80] J.J. Bosley (ed.): *Technoeconomic assessment of electric steelmaking through the year 2000.* Carnegie Mellon University, Pittsburgh (PA), October 1987.

[81] W. Reichelt, W. Hofmann: *Contiarc - ein energieoptimiertes und umweltschonendes Schrottschmelzverfahren.* Stahl und Eisen 116, no. 5, 1996, pp. 89-92.

[82] S. Eketrop: *Electrotechnologies and Steelmaking.* In: T. Johansson, B. Bodlund, R. Williams (eds.): Electricity. Efficient End-Use and New Generation Technologies and Their Planning Implications. Lund University Press, 1989.

[83] International Iron and Steel Institute: *The Electric Arc Furnace - 1990.* Brussels, 1990.

[84] UN ECE: *Steel product quality and maximum utilization of scrap.* ECE/Steel/77. New York, 1992.

[85] A. Ender, W. Scholl, R.W. Simon: *The recycling of steel - an important economic and ecological aspect of the world wide steel production.* In: The recycling of metals. Conference proceedings. Amsterdam, October 1994.

[86] A. Nijkerk: *Handboek der recycling technieken.* Novem/NOH no. 9451, December 1994.

[87] J. Bosley, J. Clark, T. Dancy, R. Fruehan, E. McIntyre: *Technoeconomic assessment of electric steelmaking through the year*

2000: Final report. Carnegie Mellon University, Pittsburg, PA, October 1987.

[88] OECD/IEA: *Energy prices and taxes. Fourth quarter 1995.* Paris, 1996.

[89] IEA: *Energy prices and taxes 1993.* Paris.

[90] Dewry shipping consultants: *World iron ore trade, shipping and costs to 2000.* Series Seaborne trade & transport 92/7. London, October 1992.

[91] R. Serjeantson (ed.): *Metal bulletin's prices & data 1996.* Metal Bulletin Books ltd., Surrey, UK, 1996.

[92] H. St. Seidenfus: *Möglichkeiten der Transportrationalisierung zur Sicherung der internationalen Wettbewerbsfähigkeit der Deutschen Montanindustrie.* Vandenhoek und Ruprecht, Göttingen, 1985.

[93] CBS: *Maandstatistiek van de industrie.* Voorburg/Heerlen, August 1996.

[94] Ministry of Economic Affairs: *Toets op het concurrentievermogen.* The Hague, June 1995.

[95] Koninklijke Hoogovens NV: *Annual report 1995.*

[96] J. Muntendam, E. Wever: *Industrie politiek in Nederland en Europa'*, Van Gorcum, Assen 1994.

[97] Economische Zaken: *Nota Kennis en Beweging*, 1995

[98] Aluminium Hardenberg B.V.: *Milieujaarverslag 1994.* Hardenberg, August 1995.

[99] CBS: *Milieukosten van bedrijven.* Heerlen/Voorburg, 1992.

[100] Ministry of VROM: *Intentieverklaring uitvoering milieubeleid basismetaalindustrie.* 's Gravenhage, 10 March 1992.

[101] A. Tabereaux: *Anode effects, PFC's, global warming, and the aluminium industry.* JOM November 1994, pp. 30-34.

[102] C. Quarles van Ufford, J. Ros: *Produktie van primair aluminium.* SPIN, January 1992.

[103] Ministry of Housing, Spatial planning and Environment: *Emissies in Nederland-1992. Trends thema's en doelgroepen.* Publication series emission registration no. 20, October 1994.

[104] Hoogovens Groep: *Milieujaarverslag 1994.* IJmuiden.

[105] RIVM: *Milieubalans 1995. Het Nederlandse milieu verklaard.* Bilthoven, 1995.

[106] Magazine Recycling Benelux, March/April 1996, pp. 87.

[107] US Bureau of Mines: *Bauxite, alumina and aluminium*. Washington DC, 1990.

[108] International consultative group: *Nonferrous Metals statistics, 1994*. Via Internet.

[109] Anonymous: *1994 annual report summaries*. JOM November 1995, pp. 6-10.

[110] Anonymous: *Selected 1993 annual report highlights*. JOM August 1994, pp. 5-7.

[111] IISI: *World steel in figures*. Brussels, 1995.

[112] Anonymous: *RSP-aluminium biedt nieuwe perspectieven*. Metaal & Techniek April 1992, pp. 18-19.

[113] W.H. Kool, F.J. Kievits: *Terugwinning van aluminum door flitsgieten*. Metaal & Kunststof 19, 19 September 1988, pp. 62-65.

[114] T. Koster: *Flitsgieten van aluminium op kantelpunt naar commercieel succes*. PT tijdschrift, January 1993, pp. 38-41.

[115] National Renewable Energy Laboratory: *New materials improve energy efficiency and reduce electricity use in aluminium production*. DOE/CH10093-140. DE92001232. September 1992.

[116] K. Grjotheim, B. Welch: *Technological developments for aluminum smelting as the industry enters the 21st century*. JOM November 1989, pp. 12-16.

[117] D. Dermer: *De Nederlandse markt voor aluminium verpakkingen*. VerpakkingsManagement 3, 3/91, pp. 46-47.

[118] G.H. Nijhof, H.E. Steenpoorte: *The separation of aluminium out of household waste using the Eddy Current technique and re-use of the metals fraction*. In: The Recycling of Metals. Conference Proceedings October 1994, Amsterdam. ASM.

[119] D.J. Gielen, J. Römer: *De grensoverschrijdende CO_2 reductie door afvalbeleid*. ECN-C-96-024. Petten, March 1996.

[120] J. Braam, W. Haije, J. Nauta: *Opzet en uitvoering minitoringsysteem Aluminium*. ECN, April 1996.

[121] T. Zervas, J.T. McMullan, B.C. Williams: *Developments in iron and steelmaking*. International Journal of Energy Research, vol. 20, pp. 69-91, 1996.

[122] B. Niemöller: Reduktion im Hochofen. In: J. Brandrup, M. Bittner, W. Michaeli, G. Menges: *Die Wiederverwertung von Kunststoffen*. Carl Hanser Verlag, Munich, 1995.

[123] H.-U. Lindenberg, H. de Haas, W. Juchhoff, J. Janz, G. Reimer, W. Weiss: *Rohstoffliches Recycling von Kunststoffen als Reduktionsmittel im Hochofen*. Stahl und Eisen vol. 116, no. 8, 1996, pp. 89-93.

[124] D. Hamels: Staalfabricage. *Trends gericht op beperking energieverbruik en lagere milieubelasting.* Bouwen met Staal 122, January/February 1995, pp. 19-24.

[125] M. Levine et al.: *Energy efficiency improvement utilising high technology. An assessment of energy use in industry and buildings.* World Energy Council, London, UK, 1995.

[126] *Nieuw zelfvertrouwen in de IJmond.* NRC Handelsblad, 7 March 1997, pp. 15.

[127] C. Badra: *Supporting steel.* Chemtech October 1995, pp. 54-59.

[128] H. Meijer, G. Flierman, C. Teerhuis, J. Bernard, R. Boom: *The cyclone converter furnace (CCF).* Paper presented at the 18th Ironmaking 2000 symposium, October 2-4, 1994.

[129] Anonymous: *Cokeless coal offers cleaner ironmaking.* Steel times November 1991, pp. 608, 614.

[130] J.P. Hoffman: Presidential address: *Oxygen-coal in-bath smelting reduction - a future process for the production of iron and stainless steel ?* J.S.Afr.Inst.Min.Metall., vol. 92, no. 8/9, pp. 253-273, August/September 1992.

[131] O. Pühringer, H. Wiesinger, B. Havenga, R. Hauk, W. Kepplinger, F. Wallner: *Betriebserfahringen mit dem Corex-Verfahren und dessen Entwicklungspotential.* Stahl und Eisen 111, no. 9, pp. 37-44, September 1991.

[132] P. Heinrich, K. Knop, R. Madlinger: *Stand und Entwicklungspotential der Direktreduktion mit dem HYL-III-Verfahren.* Stahl und Eisen 110, no. 8, pp. 75-82, 1990.

[133] Fluor Daniel: *Integrated coal gasification power plant study.* Fluor Daniel, Haarlem, 1988.

[134] H. Heckman, J. Flickenschild: *Coals for Corex. New possibilities for the coal industry.* 11th annual international coal conference proceedings, pp. 411-416. Univers, Pittsburgh, PA, 1994.

[135] J. Farla, C. Hendriks, K. Blok: *Carbon dioxide recovery from industrial processes.* RUU, NW&S rep.no. 92076. Utrecht, December 1992.

[136] C. Hendriks: *Carbon dioxide removal from coal-fired power plants.* PhD thesis, State University Utrecht, 1994.

[137] Anonymous: *Europe to remain a DRI importer.* Metal Bulletin, Monday 23 October 1995, pp. 54.

[138] R. van Duin et al.: *Monitoring van Nederlands ferro- en glasafval. Opzet en uitvoering voor peiljaar 1994.* Bureau B&G, Emst, February 1996.

[139] R. Stephenson, R. Smailer (eds.): *Direct reduced iron. Technology and economics of production and use.*
AIME, Warrendale (PA), 1980.

[140] International Energy Agency: *World energy outlook*. 1996 edition. IEA/OECD, Paris, 1996.

[141] J.O. Edström, J. von Scheele: *The balanced oxygen blast furnace compared with other alternatives for hot metal production.* Scand. J. Metallurgy 22, 1993, pp. 2-16.

[142] Central Planning Bureau: Personal communication, 1996.

[143] P. van Rijn, W. Koen, J. v/d Laar, N. Noort, J. Krol, K.J. Schmidt, C.S.M. van Stolwijk, J.N. van Straalen: *Modernisierung und Neuzustellung des Hochofens 7 bei Hoogovens.* Stahl und Eisen 112, no. 11, 1992, pp. 37-44.

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