GREENHOUSE GAS EMISSIONS REDUCTION AND MATERIAL FLOWS

Housing system analysis

Part II - Processes description

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

BUILDING MATERIALS SECTOR

1. INTRODUCTION

By signing the Kyoto Protocol in 1998, the European Union agreed to reduce its 1990 levels of greenhouse gas (GHG) emissions by 8% between 2008 and 2012. According to the commitments undertaken at European level, Belgium should reduce its greenhouse gas emissions in the 2008-2012 period to a level that is 7,5% below its level of 1990.

Building materials play a significant role in affecting global energy and/or resource use. As illustrated in table 1, building materials sector includes highly energy and capital intensive sub-sectors such as the production of steel, cement, glass and bricks, as well as sub-sectors for which energy is almost a negligible input such as the wood industry.

The industry is making significant progress in reducing energy consumption and gas emissions by investing in energy-efficient technologies. Energy efficient and cleaner technologies that are currently too expensive are allowed to become progressively more cost effective and to gain more acceptance in the market place. For each energy-using sector, a number of technologies presented in this paper will be modelled in MARKAL for projections beyond 2030.

This paper is intended to provide an overview of different topics such as the production characteristics, materials and energy use, the current situation and the future developments in technology and capacity in the industrial sectors involved in the major building materials life cycle. The methodology used is shown in figure 1. The target is to quantify GHG emissions per tonne of material generated by the existing Belgian processes with their future evolution and by technological options.

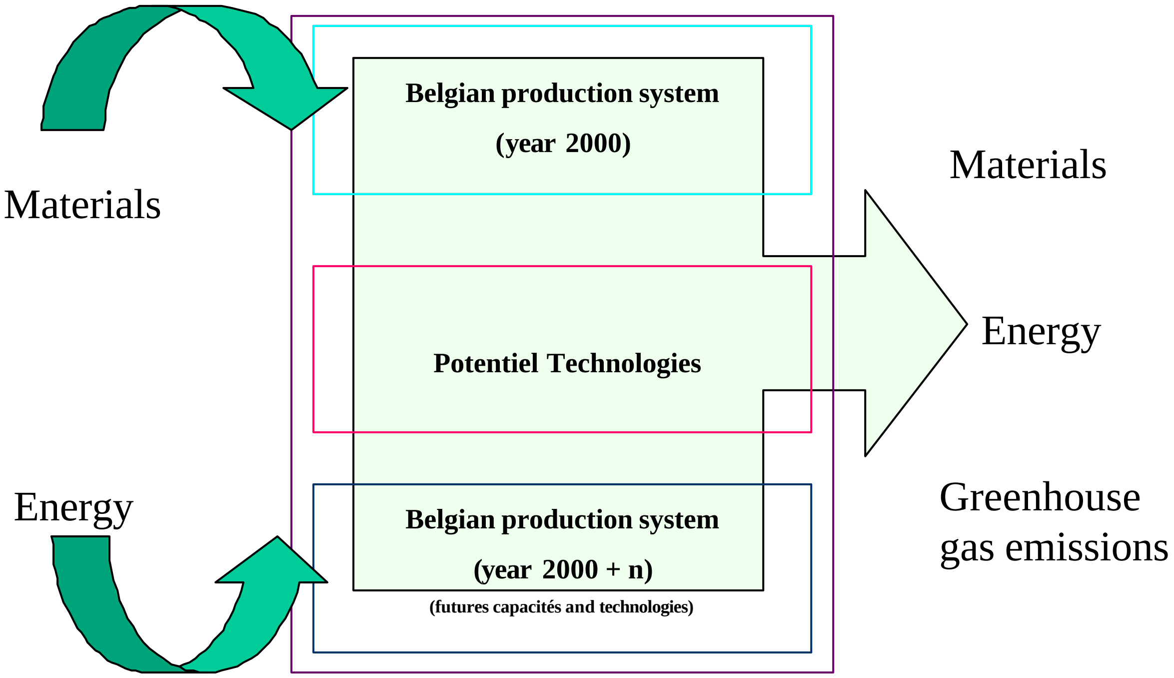

Figure 1.- Methodology to characterise the Belgian production system

The content of this document is the following for each industrial sector studied:

The **first section** presents briefly the material flows of each sub-sector in Belgium. It incorporates general statistics compiled from information published by some national, European and/or international federations along with other industrial sources.

The **second section** contains a brief characterisation of the materials and products processed.

The **section 3** describes the main production routes in the Belgian industry, the fundamental processes and their relevant characteristics. Then alternatives for production and energy consumption of the Belgium industry existing world-wide are analysed.

New and emerging technologies are thus identified in **section 4**.

The **fifth section** gives an overview of the current and future capacity in the main Belgian industries. This section incorporates data compiled from Institut Wallon annual and punctual surveys of individual manufacturing plants to analyse the current situation and data from the activities reports of the largest companies to estimate future investments in technology and capacity.

The **section 6** is designed to provide background information on the greenhouse gas (GHG) releases and to identify mitigation options. In this section, GHG emissions are quantified by process using IPCC (Intergovernmental Panel on Climate Change), Corinair and/or calculated emission factors for Belgium. The main sources of information are recent literature and the Belgium energy inventories which focus primarily on the on-site energy and materials consumption reported by each industry.

Emission estimates presented here are not meant to be definitive inventories for the Belgian building materials industry. Estimates have the sole purpose of establishing an order-of-magnitude reference point.

Then GHG emissions mitigation options are discussed using the IPCC list of improvement options as a reference. This list include “fuel switch”, “increased energy efficiency”, “CO2 removal and storage”, “recycling and reuse” and “dematerialization and materials substitution”.

Potential technologies that will reduce GHG emissions are include in the “increased energy efficiency and cleaner technologies” topic.

Finally, other environmental impacts are presented.

Each chapter ends with an appendix that contains summary information on the energy and material balance by process and by technology.

Text within each topic and each industrial profile was researched from a variety of sources, and was usually condensed from more detailed sources pertaining to specific topics. This report provides a synopsis of each issue and references where more in-depth information can be found are listed at the end of the report.

Table 1 summarises an estimation of the energy consumption and the CO2 emitted in Belgium by each industrial category of the building materials sector in 1995.

The iron and steel sector is responsible for 31%, the cement sector for 11% and the glass sector for 3% of the CO2 emitted by industry in Belgium in 1995.

	Total energy consumption		CO2 Emissions			**Total CO2 Emissions (kt)**
	Combustion (TJ)	Electricity (GWh)	Combustion (kt)	Electricity (kt)	Process (kt)	
Iron and Steel	106.805	5.721	13.413	1.857	2.310	**17.580**
Cement	29.710	1.026	2.565	389	3.339	**6.293**
Glass	14.780	736	971	279	190	**1.439**

Table 1.- Estimate Belgian industrial energy consumption and CO2 emissions in 1995
Source: ECONOTEC and INSTITUT WALLON

The consumption of materials in the building sector is very important from a CO2 emissions point of view. Therefore, more durable products play a significant role in climate change.

For example, an increased use of wood products can both stimulate the growth and carbon sequestration and increase the carbon storage effect[1], while decreasing the emissions through material substitution.

The results of the present study on the production system have as well been used to quantify emissions by product in the consumption system[2].

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[1] In the framework of the ongoing international negotiations for the implementation of the agreed measures of the Kyoto Protocol, wood products are being studied as a sink and store of carbon dioxide.

[2] See Institut Wallon, 2001, Greenhouse gas emissions reduction and material flows, Housing system analysis – Part I : Detailed description of the system and evaluation of the potential of emissions reduction.

2. THE IRON AND STEEL INDUSTRY

2.1. Steel production and consumption in Belgium

In the last 30 years, technological development in the iron and steel industry has been characterised by the dominance of integrated steel production followed by the increased use of the electric-arc-furnace which accounted for respectively 79 per cent and 21 per cent of the Belgian production of crude steel in 1998.

The steel sector is very transport intensive. The integrated steel industry in Belgium depends on a substantial part of its raw materials (e.g. iron and coking coal) from overseas markets. Despite the growth of scrap-based steelmaking, iron ore remains the principal source of iron for steel production. In 1998, consumption of scrap in Belgium was 3,8 million tonnes compared to a apparent consumption of 14,3 million tonnes of iron ore imported (pellets included) to produce 8,6 million tonnes of pig iron. These 8,6 million tonnes of pig iron provided the principal basis for the 11,4 million tonnes of crude steel produced in Belgium.

The apparent steel consumption in Belgium-Luxembourg was 4,4 million tonnes in 1998.

In 1998 Belgium was in the 18th position of the major world steel-producing countries being Cockerill Sambre the 25th of the largest world steel-producing companies rank with a output of 6,7 million tonnes of crude steel from which 4,2 million tonnes were produced in Belgium (the activities of Cockerill Sambre and EKO Stahl together with their subsidiaries comprise the Walloon and German units).

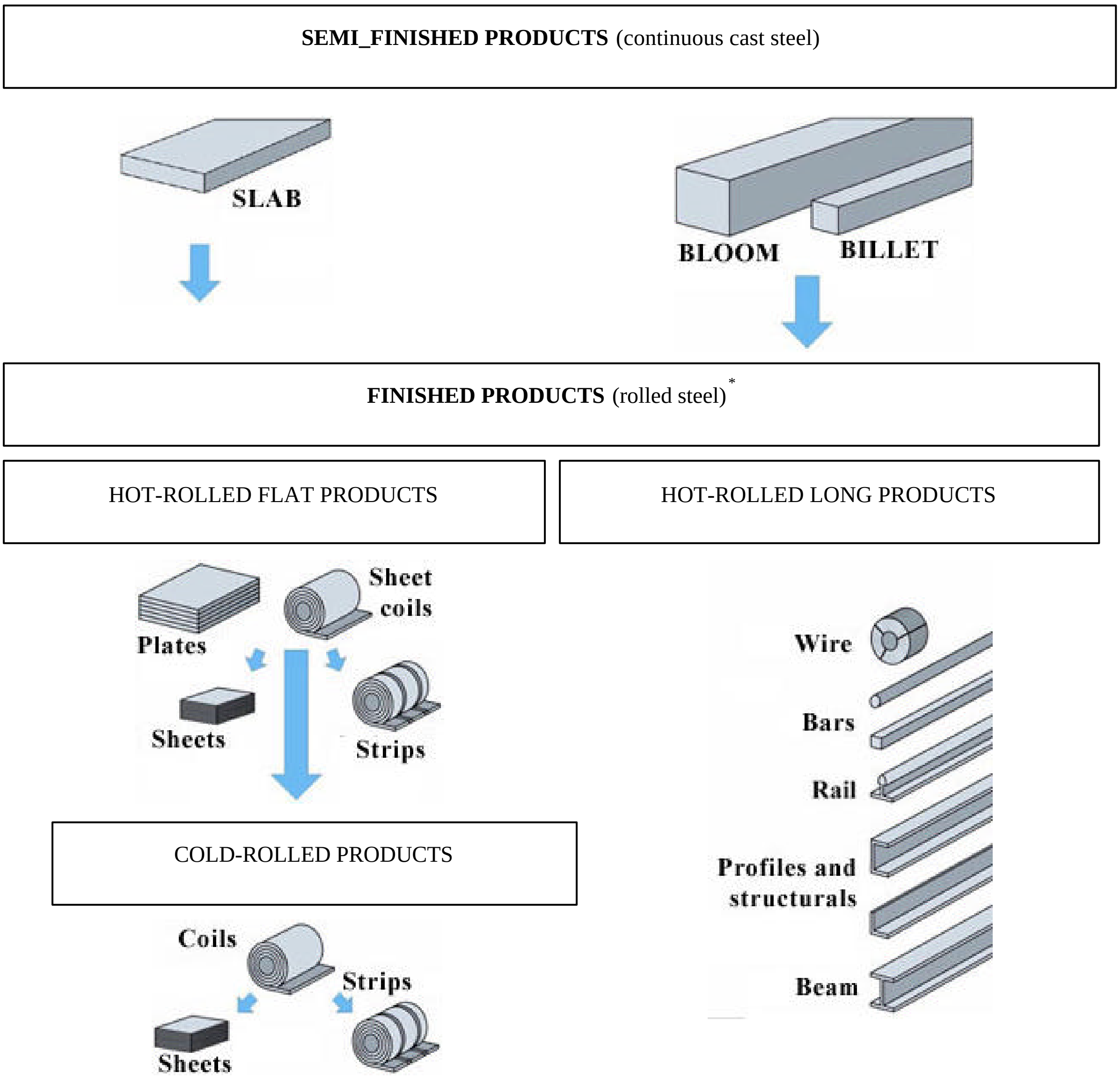
At the end of 1998, the Belgium steel industry employed 21.015 people.

2.2. Product characterisation

The metals market is largely dependent on two or three big end users such as car manufacture, packaging and construction.

As shown in figure 1, semi-finished products are slabs, which have a rectangular cross-section, or billets or blooms, which have a square cross-section. They are huge basic steel shapes that will subsequently be processed to create finished products such as sheet steel for auto body parts and appliances or wires to make reinforced concrete, etc.

Flat products are in general used in the production of automobiles and appliances, such as refrigerators, while long products are generally used in infrastructure.



* Not all steel products are formed by rolling. They can also be forged, cast from molten steel, or made with powdered alloys.

Figure 2.- Semi-finished and finished steel products
Source: Usinor

2.3. Main production routes in the iron and steel industry

Steel is manufactured by “integrated” and “non-integrated” producers. Integrated producers generally make steel from iron ore, coal, and limestone as the basic ingredients, using coke ovens, blast furnaces (which produce an intermediate product called pig iron), and basic oxygen furnaces (which are used to process pig iron into steel). Non-integrated producers make steel by melting and refining ferrous scrap at generally smaller scale electric-arc-furnace (EAF) facilities (often referred to as minimills).

Basic oxygen furnace (BOF) facilities are generally used to produce high volume and/or high quality flat-rolled carbon steel products, while EAF facilities have traditionally focused on producing either carbon steel bars, rods and structural shapes, or high value speciality steels (such as stainless and tool steel).

When making steel with BOFs, cokemaking and ironmaking precede steelmaking. Coke, which is the fuel and carbon source, is produced by heating coal in the absence of oxygen at high temperatures in coke ovens. Pig iron is then produced by heating the coke, iron ore, and limestone in a blast furnace (BF). In the BOF, molten iron from the blast furnace is combined with flux and scrap steel and high-purity oxygen is injected.

Conversely, the input material for the EAF is primarily scrap steel, which is melted and refined by passing an electric current from the electrodes through the scrap.

In both processes, the molten steel is then formed into semi-finished products that are rolled into finished products. Rolling operations may require reheating, rolling, cleaning, and coating. The heat treatment that semi-finished products undergo is known as "hot rolling". More than half the hot-rolled sheet is subsequently rolled again at ambient temperatures in the process known as "cold rolling". It can then be coated with an anti-corrosion protective material.

Iron and steel products include unfinished items such as bars, strips, sheets and formed products such as steel nails, spikes, wire, rods and pipes. Depending on the equipment used, saleable products may also include by-product coke, blast furnace slag and products derived from chemical recovery of volatile compounds in the coking process such as gas, coal tar and distillates for sale or internal use. Blast furnace gas is produced during the combustion of coke in blast furnaces. It is recovered and used as a fuel partly within the plant and partly in other steel industry processes or in power stations equipped to burn it. Also included here is basic oxygen furnace gas which is obtained as a by-product of the production of steel in an oxygen furnace and is recovered on leaving the furnace.

Due to the high quality of steel made, BOF technology accounts for most of the production of flat sheets and plates. The EAF, which requires a lower capital intensity and provides a greater operational flexibility, was in the past primarily aimed at long products (including special steel products) because the quality of the scrap was not high enough to produce flat products. Driven by new technological developments (availability of scrap substitutes and, more important, the introduction of new casting techniques), it has started to be used also for flat steel production. This requires generally either high quality scrap or the addition of "virgin" materials like sponge iron (DRI), cold pig iron or hot metal from direct iron reduction plants, blast furnaces or smelting reduction plants.

2.4. Technological Perspectives

The major oil shocks of the 1970's and the subsequent increasing cost of energy have prompted the industry to improve its operational efficiency by investing in new technologies and shutting down old plants. In view of the high cost of new equipment and the long lead-time necessary to bring it into line, changes in production methods and products have usually been made gradually.

The introduction of new equipment and the necessary retrofitting of other processes impose direct and indirect costs on the industry. Even proven technologies that improve productivity, such as the continuous casting process, have only been adopted over long periods of time, indicative of the fact that steel producers have had difficulties in financing major investments.

Since the 1970s a reduction in total specific energy consumption has been achieved. These results were reached directly by innovations such as continuous casting which eliminates a reheating step and, indirectly, by reducing the amount of crude steel needed for each tonne of finished steel products. At the same time, the growing use of continuous casting, combined with other increases in process and product efficiencies, improved the yield of crude steel for steel products.

Because significant new blast furnace capacity is not expected, steel plants must find ways to extend liquid pig iron production to meet demand. This section identifies several ways to extend production without increasing blast furnace capacities by the use of new emerging processes and the growth of the EAF route. The new processes, shown schematically in this section, include coal-based smelting process to replace the blast furnace and coke oven, direct iron reduction processes as a scrap substitute and near net shape metalworking operations such as thin slab casting process to save energy in the reheating step and direct strip casting process to replace the continuous caster and hot strip mill. Finally, the trend towards the growth of minimills using electric arc furnaces will be discussed.

2.4.1. Ironmaking technologies: Direct Smelting and Direct Reduction Processes

There are three basic methods of producing iron: the blast furnace method, iron smelting and direct reduction. The blast furnace route, shown in paragraph 2.3, produces all of the iron in Belgium. Ironmaking, the first step in steelmaking, represents the most capital and energy intensive process in the blast furnace method. In the next few years, however, several new direct reduced iron and direct iron smelting plants could be commercially available. Three examples of smelting reduction processes (COREX, CCF and SIDCOMET) and the major direct iron reduction processes (Midrex and Hyl) will be presented in this section.

The ultimate objective in the iron smelting area was to develop a coal-based process that produces liquid iron directly from coal and ore fines or concentrate. Therefore, smelt reduction processes currently under development combine coal gasification with the direct reduction of iron oxides. In this way, production of coke is abolished and the demand of ore preparation reduced, replacing the whole route from coke, sinter and pellet production to the blast furnace and integrating three processes in one.

Direct reduction processes yield solid iron product from ore or pellets using natural gas or coal as fuel and reducing agent. The oxygen in the iron oxide combines with the carbon in the reductant, just as in the blast furnace, but the reduction in to pig iron is not complete, leaving a metallic sponge iron product that is 80 % or more iron. Direct reduction processes are similar to smelting reduction processes, the difference is that the partially reduced iron is not immediately converted into liquid iron, but is sold as solid resource (so-called sponge iron or DRI) for further processing. DRI is available in pellet and lump forms or in a compacted form known as hot briquetted iron (HBI). Most DRI is primarily used as a scrap substitute in the electric arc furnace (in this case, the DRI/EAF combination replaces the BF/BOF combination), while some forms may be used in the basic oxygen furnace and blast furnace as a process coolant.

Comparing smelting and reduction processes to replace ironmaking in the blast furnace route, liquid iron is preferred to solid iron because there is no gangue and it retains its sensible heat. In addition, coal is obviously preferred over coke or natural gas because of its abundance and lower cost.

The elimination of cokemaking and agglomeration reduce significantly capital costs. Coke plants consume high grade coking or metallurgical coal types, which are more expensive than steam coal (used in power generation). Smelt reduction technology makes it possible to use steam coal, thereby reducing fuel costs compared to a blast furnace. Smelt reduction has dramatically lower capital costs, but has other inherent advantages, e.g. resources use (e.g. less expensive coal than current metallurgical coal), pollution control and favourable economics at smaller capacities compared to conventional technology. Various pilot-plants exist world-wide, and the first commercial small-scale applications have been seen.

The COREX process, which uses coal directly to produce liquid hot metal, is the only commercially applied smelt reduction process but it is still capital extensive, requiring pellets or lump ore and producing excess energy that must be used for the process to be economical.

The processes that appear to possess most of the required attributes are the iron bath smelting processes, which have been under development over the past decade and have been only demonstrated through laboratory and pilot plant studies. These include the CCF (Cyclone Converter Furnace) processes developed by Hoogovens Staal BV in the Netherlands, the Direct Iron Ore Smelting (DIOS) process under development in JISF (Japan), the AISI Direct Steelmaking process studied in a pilot plant at Universal, Pennsylvania, the HISmelt/KSG process in CRA (Australia) and Kl'ckner (Germany), the ROMELT process developed in Russia and the CleanSmelt process developed in Italy. The principals of the smelt reduction processes have been proven on large scales, and the construction of large sized demonstration plants is planned for the near future. The principals of all processes are similar, although differences occur, especially in the pre-reduction phase where ores and coal are mixed. An overview of the most advanced bath smelting process, the CCF process, is given here.

Table 2 summarises the characteristics (energy consumption and costs associated with the processes) and status of the major direct smelting and reduction processes.

Electricity conversion efficiency is assumed to be 40%. The total energy consumption should be compared to 17.8 GJ/tonne hot metal (thm) for a modern large scale blast furnace (including coke oven and sinter plant) and an estimated capital costs of 305.5 euro/thm (12325 BF/thm). The energy efficiency is generally higher than for the conventional blast furnace technology.

Process	**Developers**	**Status**	**Estimate Specific Primary Energy Consumption (GJ/t iron)**	**Estimate Investments in euro/t capacity (BF/t capacity)**
DRI	Midrex Direct Reduction Corporation, HYL	Commercial production	11	132 euro/t sponge iron (5310 BF)
COREX	Voest-Alpine AG and their subsidiary Korf Engineering at Kehl, West Germany	Commercial operation (300000 thm/yr)	17-20 or 29	194-232 euro/thm (7850-9340 BF) (new plant)
CCF	Hoogovens (Netherlands), Ilva (Italy)	Experience at 175000 thm/yr. Pilot plant planned (350000 thm/yr)	15 or 20,1	139-167 euro/thm (5600-6725 BF)
SIDCOMET	Sidmar (Belgium)	Demonstration plant. Two pilot plants planned (750000 thm/yr).	n.a.	132 euro/thm (5330 BF)

Table 2.- Energy consumption and costs associated with the reduction processes.

Direct reduction processes require pellets or lump ore, have relatively high capital costs, and require relatively large production units (one million tonnes per year) to be economical. However, commercial production of DRI has grown from its origins in the 1950s to the current level of 132 modules operating in 21 countries. Gas-based processes comprise 92% of total DRI production, with two processes accounting 89% of direct reduction iron production world-wide: the Midrex process accounting for 63% and the HYL process 26% of the total. Many DRI plants have been built adjacent to the steelworks as a subsidiary to the steel company; only 15 of the 132 plants are merchant facilities serving the open market. DRI production is most feasible economically in locations where either cheap gas or coal is available. The estimated energy consumption of DRI processes is approximately 11 GJ/tonne sponge iron[3].

However, since the beginning of the nineties, DRI has increasingly emerged as a cheaper, low-residual iron feedstock for EAFs, which have traditionally relied almost entirely on ferrous scrap feed. The main stimulus behind the interest in DRI has been the increasing popularity of the EAF and the 'mini-mill' set-up as the favoured steelmaking option compared to the traditional and much less flexible blast furnace/basic oxygen converter. This, however, has been creating a problem with regard to availability of low-residual scrap, resulting in upward pressure on high quality scrap prices and leaving DRI, traditionally the 'expensive alternative', as a much more competitive consideration.

The second main determinant has been the increasing production efficiency of existing steel plants which, in the light of improvements such as continuous casting and near net shape casting (see paragraph 2.4.2.), has been constraining the supply of low-residual domestic scrap, traditionally the prime source of EAF feed, as these technologies (where the cast surface becomes the finished part surface) lead to the necessity of defect-free castings.

One of the major factors influencing the value in use of DRI products is the degree of metallization, defined as the ratio of percentage metallic Fe to percentage of total Fe. Typical metallization values for DRI range from 88 to 93%. The other major factor influencing the value in use of DRI is the gangue content. While most of the iron oxide is reduced to metallic iron, silica, alumina and phosphorus are not reduced and remain in the final product as oxides. Gangue consists of both acidic (SiO2, Al2O3, TiO2) and basic (CaO, MgO) components. The acidic components, if excessive, can be detrimental to maintenance of sufficient slag basicity for slag foaming, low refractory wear and adequate chemical activity to facilitate dephosphorization and desulfurization[4].

The COREX process is a two-stage operation in which DRI from a shaft furnace like that used in the Midrex and HYL process is charged into a final smelter-gasifier. Reducing gas for the shaft furnace is produced by partial combustion of coal with oxygen in the fluidized bed of the smelter-gasifier. The energy needed to complete the reduction of the DRI and produce the hot metal and slag is provided by the partial combustion.

COREX uses approximately one tonne of coal per tonne of hot metal, with approximately 45% of the total energy input used in ironmaking and the rest going to export fuel gas. The hot metal produced has carbon and silicon contents similar to blast furnace hot metal. However, the sulphur content is much higher because nearly all of the sulphur in the coal enters the slag and hot metal. In this connection, organic sulphur in the coal gasifies and is absorbed by the DRI and returned to the smelter-gasifier as iron sulphide.

The first commercial scale COREX plant was built for ISCOR in South Africa during 1985 through 1987 by Voest-Alpine Industrieanlagenbau. The plant, rated at 300,000 tonnes per year, was commissioned in November 1989 after testing, modification and operation following the start-up in 1987. Since commissioning, the COREX plant at ISCOR has performed very well at the design specifications. The first commercial COREX plant operating in South Africa shows an estimated net specific energy consumption of 17 GJ/tonne pig iron, which is comparable to that of a modern blast

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[3] The Basic Metal Industry and its Energy Use. Prospects for the Dutch energy intensive industry. D.J. Gielen and A.W.N. Van Dril. ECN, March 1997.

[4] Survey of EAF steelmakers conducted in 1999 by the IISI Committee on Technology.

furnace, including ore preparation and cokemaking. A second COREX plant was constructed for POSCO at their Pohang Works in Korea in 1998.

The CCF, initially developed by Hoogovens Staal BV in the early 1990s, is a process for melting and pre-reducing iron ore fines as feed for a bath smelter. The ore fines, introduced at the top of the vertical furnace, are initially melted and then reduced to 15–20% by the rising smelter offgas. Melting occurs due to the high temperatures achieved by combustion of the rising offgases with oxygen introduced through swirl injectors. The injectors promote mixing of the combusted gas with the ore fines for improved heat transfer. Final reduction occurs in a bath smelter. Hoogovens used a smelter for a 0.4–1.0 million tonne/year plant. The estimated net specific energy consumption of CCF process is approximately 20 GJ/tonne hot iron[1].

The SIDCOMET process, developed by Sidmar in Belgium, is a combination of a direct reduction of iron ores with coal as the reducing agent and a melting operation allowing to transform the direct reduced sponge iron into hot metal, suitable for further treatment in a classic BOF steelshop. The direct reduction of the iron ores takes place in a rotary hearth furnace. An important advantage of the process is that the raw materials do not need any preconditioning, such as pelletisation. The raw materials, iron ore, coal and fluxes, are mixed by mechanical devices, allowing an intensive contact between them. This leads to a low coal consumption, it avoids thermal shocks on the hearth floor, and permits operation with a thick layer of raw materials, an optimal retention time and consequently high production rates. The gaseous atmosphere within the burden and close to the layer avoids reoxidation of the sponge iron. The produced sponge iron is directly discharged by gravity in an electric furnace, thus avoiding oxidation of the sponge iron, and allowing to make use of the important latent heat of the prereduced iron. The sponge iron, with a metallisation rate of over 90 % is melted and produces a hot metal that is comparable to blast furnace hot metal. It is poured in usual torpedo ladles, and transferred to the BOF steelshop.

Capital costs of modern blast furnace-based plants are high. The investments involve coke plants, ore preparation (sintering, pelletization) and the blast furnace. Blast furnace plants are estimated to cost approximately 305.5 - 324 euro/thm (12325 – 13075 BF/thm) annual capacity.

Until today most of the global hot metal production is realised through the classic blast furnace route. According to IISI, direct reduction to produce DRI makes only a very small contribution to the EU iron production (0,3% in 1990). Thus far, direct reduction processes have proved profitable only under very tight conditions, such as extremely low natural gas prices and availability of rich, preconditioned iron ores. The capital required for a commercial coal gasification/DRI production plant are estimated to be 131.6 euro/tonne sponge iron (5310 FB/t) annual capacity[1].

The investments required for the COREX-process are estimated to be 194 – 232 euro/tonne (7850 – 9340 BF/t) annual capacity (excluding ore agglomeration plant). Costs associated with the construction and start-up time must be taken into account. The construction of an integrated primary steel plant may take over 5 years, while the construction of the COREX-plant in South Africa took approximately 3 years, resulting in reduced capital requirements[5].

The capital required for a commercial sized CCF plant are estimated to be 139 – 167 euro/tonne (5600 – 6725 BF/t) annual capacity. The operating costs of a smelt reduction plant will depend on local conditions, but may be expected to be significantly lower due to the abandoned processes. The reduction of operation and maintenance costs for the CCF process in Western-European conditions is estimated to be 16.7 euro/tonne pig iron (675 BF/t).

The capital expenditures of a typical SIDCOMET installation with a capacity of about 750,000 tonnes of hot metal per year will amount to some 99 million euros (4 billion BF), resulting in 132 euro/tonne (5330 BF/tonne hot metal) annual capacity. SIDCOMET will produce hot metal at a competitive cost

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[5] ATLAS Project – Thermie Programme. European Commission.

under Western European conditions, thanks to the use of coal as reducing agent. Moreover, the iron ore does not need any preconditioning before being charged in the SIDCOMET furnace[6].

Direct reduction processes are currently used to produce iron mainly for use in an electric arc furnace. Driven by growth in electric furnace steel production (see paragraph 2.5.3.), the movement of EAF producers into higher quality products and an insufficient supply of prime scrap, world-wide DRI production is increasing. The use of all forms of alternate iron, including DRI, HBI, merchant pig iron and hot metal, has risen substantially and is approaching 20% of the charge for EAFs world-wide.

Smelting processes could represent as well a portion of production and can replace older blast furnaces or add incremental hot metal to integrated plants. Aside from the COREX process already in use, several iron smelting pilot plants have been operated, but commercialisation is several years away. Most of these processes have proceeded to the pilot-plant scale but no plans to date have been made for commercialisation. It is expected that the direct smelting technology will be developed to the market introduction status by the year 2010. Countries which are likely to deploy the technology at an early stage are USA, Japan, Netherlands and France[7].

2.4.2. Casting technologies: thin slab and strip casting

Steel casting processes represent one of the major areas of technological development within the steel industry. New technologies such as thin slab and strip casting are under rapid development and commercialisation.

In conventional steelmaking, steel is first cast and stored. The cast steel is reheated and treated in the rolling mills to be reshaped. On one hand, current technology development is directed towards further reduction of the cast thickness in order to abandon the need for reheating and the (hot) rolling stand. The technology is called thin slab casting. On the other hand, new technologies imply the direct casting of the metal into (or near to) the final shape, e.g. strips or sections, replacing hot rolling by casting and the first rolling steps.

In thin slab casting technology, instead of slabs of 120-300 mm thickness produced in a continuous casting, slabs of 30-60 mm thickness are cast. The cast thin slabs are reheated in a coupled furnace, and then directly rolled in a simplified hot strip mill.

A variation of thin slab casting is direct rolling or hot charging of the steel in the rolling mill through a technology called strip casting. This will eliminate reheating and the hot stand on the rolling mill. This option is already technically feasible, but will require large, expensive renovations in the lay-out of existing steel plants. In new steel plants the location of the rolling plants can be optimised to reduce internal transport and reheating needs.

The current state of the strip casting technology both inside and outside of the European Union is at the prototype stage prior to demonstration. It is expected that deployment will be initially confined to the EU and USA by the year 2010.

The 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.

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[6] SIDMAR Activities Report.

[7] Based on a recent technological Survey carried out by IRSID-Institut de Recherches de la Sidérurgie (France).

2.4.3. Growth of EAF plants

One of the major causes of the reduction in energy needs by the iron and steel industry is related to the use of scrap as raw material. Increasingly, recycled metals are becoming a major part of the total metal supply of this industry. Steel produced from scrap requires 60 per cent less primary energy than steel produced from ore. Over 40 per cent of total world steel production is now based on recycled rather than virgin materials, which makes it the most recycled of all materials.

Traditional EAF-based steelmaking included the production of specialty, stainless and engineering steels as well as reinforcing bar and wire; over the past 20 years, production has expanded to include high-end long products, beams, structurals and wire rod. The emergence of thin-slab casting and direct rolling technologies (shown in paragraph 2.4.2.) has facilitated the growth in the EAF-based production of flat steels. These evolutions have placed increasing importance on the purity of raw materials, as the level of residuals in steel produced from a scrap-based EAF shop may be higher than for steel produced via the integrated route. Metallic residuals can be controlled through scrap segregation, selection and blending or by dilution using DRI, HBI, pig iron or hot metal (see paragraph 2.4.1.).[8] Therefore EAF producers increasingly combine scrap with DRI and/or other virgin iron in order to extend their raw materials base, and following the drive towards higher value-added products. However, at this time, EAF plants cannot produce the full range of products made by integrated steelworks. More than half of the market for quality steel products remains beyond EAF plants capability[9].

Consensus responses to a survey of EAF steelmakers conducted in 1999 by the IISI Committee on Technology, were used to project the most likely trends for continued evolution of the EAF steelmaking process, and to predict the characteristics of a typical operation in the year 2010.

The results indicate that these shops will continue to produce the traditional specialty and low-end long products steels, but will gain an increasing presence in the sophisticated carbon steels for both the long and flat product areas. New sources of iron, including DRI, HBI, hot metal and pig iron will be utilised to supplement the scrap charge. EAF-based production of flat products will no longer be confined to the minimill sector, but will begin to appear as new additions to existing integrated mills. Operating efficiencies will continue to improve on a similar trend to the past 10 years.

According to some experts, the demand for steel will probably exceed supply estimates in the next decade in OECD countries and steel production will continue to experience strong growth of EAF plants gaining market share at the expense of the integrated route. EAFs will produce 40 percent of the world's liquid steel in 2010, compared to 33 percent today[10].

EAF technology is not only cost-effective but also the CO2 emissions are significantly lower than for blast furnace steel technology.

Charging hot metal is the future of EAFs. Virgin iron enables EAFs to produce wire rod, flat-rolled, and other higher-value products. The virgin iron units require less electrical energy in the melt shop and contain fewer residuals than scrap; their lower nitrogen content—the residual element most difficult to control—is particularly useful. DRI is a relatively pure material which dilutes contaminants in the scrap and improves the steel quality. The problem is that DRI production is very energy-intensive. DRI is commercialised in countries with large supplies of cheap gas or coal that is not suitable for coking, such as Mexico, Venezuela and India.

A basic flow diagram of Iron and Steel manufacturing main routes and emerging technologies is shown in Figure 3.

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[8] Survey of EAF steelmakers conducted in 1999 by the IISI Committee on Technology.
[9] OECD
[10] The IISI Delphi Survey

2.5. Current and future technology and capacity

The capacity in Belgium-Luxembourg in 1996 was 18,7 million tonnes (production 17,1 Mt, capacity utilisation 91%).

Table 3 presents the expected evolution of production capacity in the Belgian iron and steel industry estimated from the investments plans of major facilities (synthesised bellow).

	1995	2000	2005	2010
Capacity (million tonnes)	13	13	16	16

Table 3.- Iron and steel production capacity

2.5.1. Cockerill Sambre

Cockerill Sambre Group carries out hot steelmaking integrated operations at Liège and Charleroi, including Carlam (75% Cockerill Sambre, 20% Sollac and 5% ALZ), as well as cold-rolling, tinning, galvanisation and organic coating operations in operational centres located in the Liège basin.

Cockerill Sambre officially became part of the Usinor-group in April 99.

The development of the industrial plan of Cockerill Sambre in synergy with Usinor, which plans to increase capacity at Cockerill, has led to the acceleration of the installation of new equipments designed to provide increased profitability of the hot lines at Liège and Charleroi. The Liège plants of Cockerill will provide Usinor's Florange site (Lorraine) with semi-finished products and Cockerill's Carlam (Charleroi) plant will receive stainless slabs for rolling from Ugine Isbergues. The principal investments are a second continuous casting line at Chertal (Liège) and a third reheating furnace at Carlam.

Detailed studies were undertaken from November 1998 to carry out these investments within a very short time in order to ensure their commissioning by the end of 1999 for the furnace and 2000 for the continuous casting machine.

Some 144M euros (5810M BF) will be invested in the second continuous caster at Chertal (Liège). It will be operational in the 4th quarter 2000 and will bring raw steel capacity from 2.4 Mt/year to 3.5 Mt/year.

By installing the third reheating furnace, hot rolling capacity at Carlam has been brought up from 3.2 Mt/year to 4.2 Mt/year.

Upgrading investments are being carried out at the coating lines of Flemalle and sister company Beautor. The welding capacity of Cockerill Sambre Tailored Blanks is being enlarged in an investment of some 10M euro (403,4M BF).

Concerning technology progress, the major decisions taken to date at Cockerill are as follows:

- The reconstitution of the coke batteries is not envisaged.
- The alternative pig iron production technologies will not be retained as in their current state of development they are not economical. In any event, studies carried out in 1998 indicate that the conversion of ferrous metal co-products into pre-reduced iron is an attractive and economic way of reducing the environmental impact.

- The reconstruction of the blast furnaces is envisaged.
- The application of thin strip continuous casting technology at an industrial level of operations is not foreseen before the years 2005 to 2010.

2.5.2. Sidmar

The SIDMAR steelworks in Gent, which is part of the Luxembourg based Arbed group, is a classic example of a fully integrated coastal plant, disposing of two blast furnaces fed by integrated coking and sintering plants, a BOF steelshop, a wide hot strip mill and cold rolling and coating lines.

The crude steel production at SIDMAR has been in equilibrium with the output of the rolling mills until the mid-nineties. While the hot strip mill has an intrinsic capacity of 5.5 million tonnes per year, the capacity of the blast furnaces today limits the crude steel output to some 4 million tonnes per year and in the BOF-steelshop SIDMAR has only one continuous caster with the same capacity of 4 million tonnes per year.

Temporarily SIDMAR has solved this problem through the yearly purchase of up to 1 million tonnes of slabs from other steel producers. However, this solution has a negative impact on the production costs, since purchased slabs are significantly more expensive than the ones produced in-house. Moreover, the important swings in the availability of slabs on the world market make this supply chain unreliable in the long run.

That's why SIDMAR was very much interested when the Benelux research centre CRM presented its "COMET"-process, a new direct reduction process using coal as the reducing agent ("Coal-based Metallisation). Together with other steel producers and an engineering firm, a research syndicate was established in order to build a demonstration plant based on the COMET principle. If this process would prove feasible, it could have given SIDMAR the extra steel production it so much needs. Unfortunately, the productivity of the COMET process appeared to be insufficient: the research syndicate was dissolved in early 1998. However, SIDMAR continued on its own research with the demonstration plant, and after a few months of further experiencing, a breakthrough occurred through some fundamental changes of the COMET process. SIDMAR renamed the process "SIDCOMET" and applied for a patent.

Additionally, a number of additional investments are planned to allow the blast furnaces, the BOF-steelshop and the utilities services to adapt themselves to the increased production levels.

The two SIDMAR’s blast furnaces will be relined respectively in 2001 and 2003 and SIDMAR will take the opportunity to increase the hearth diameters of both furnaces (blast furnace A from 10 to 11 m and blast furnace B from 10,5 to 10,75 m). This will increase SIDMAR's crude steel capacity by 0,6 Mt/year.

In November 99, the Board of Directors of SIDMAR Gent has given the green light to an investment project of 218 million euro (8780 million BF) for the building of a second continuous slabcaster that will allow Sidmar to balance the capacity of its BOF steelshop with that of its hot strip mill. The new caster will allow the company to participate more actively in the development of new steel grades, such as the high-strength steels that will become ever more important for the automotive industry, which is looking for lighter carbodies to produce cars that consume less fuel. With only one continuous caster, SIDMAR does not have sufficient capacity today to follow this trend at the speed required by its customers. The caster should be commissioned by the month of September 2001. It will create some 135 new jobs in the SIDMAR steelworks.

Concerning technology, Sidmar plans to increase its raw steel capacity from 3.7 Mt to 6.0 Mt by 2003 by:

- building two 750 kt/year ‘Sidcomet’ coal based DRI-smelting plants;
- revamping its two blast furnaces to increase capacity by 600 kt/year;
- installing a new continuous caster.

This programme represents a 450M euros (18153M BF) investment.

The company is also expanding its coating capacity: following the start-up in February 98 of Galtec 1, a Sidmar - Hoogovens joint-venture at the Gent plant, the two partners started building a second line (Galtec 2) at IJmuiden which is scheduled to come on stream in April 2000. When complete, the two companies will exchange shares becoming sole owners of the respective national lines (Galtec 1 is then to be renamed Sidgal 1). Sidmar decided to build two more new HDG lines at its Gent site: Sidgal 2 (in joint venture with Luxemburg based Giebel), which will have a 240 kt/year capacity and Sidgal 3 (400 kt/year). The start-up of these two lines is scheduled in mid 2000.

Sidmar will increase its tailor welded blanking capacity in a 63.02M euros (2542M BF) investment in new facilities at Gent. The project will be carried out in four phases completed between 2000 and 2002, comprising in total two blanking lines and 10 welding lines.

2.5.3. Duferco

Former Usines Gustave Boel, which operated under a 50/50 joint venture with Hoogovens in 1998, but experienced social and technical problems, was placed in receivership in October 98 and taken over in May 1999 by the Swiss-Italian trading house Duferco and the Walloon government’s steel holding company. The new owner plans an investment package of some 60M euros (2.5 billion BF) for galvanising and painting plants at La Louvière, to be operational in 2002. The EAF and cold mill at La Louvière will continue to operate. Approximately 570 jobs will be lost at former Hoogovens-UGB, but 100 will be transferred to Duferco Forges de Clabecq, integrated producer, which was also rescued by Duferco in November 1997, with production restarted in January 1998. Currently, Duferco operates with 1120 workers at La Louvière and 950 workers at Clabecq.

A investment of some 297.5 millions euros (12000 millions BF) is planned, out of which 49.6 millions euros (2000 millions BF) are used for casting equipment optimisation at La Louvière. The major decisions taken to date are to use again the small blast furnace (number 2) in order to increase the crude steel capacities at La Louvière and Clabecq from 1,8 Mt/year to 2,5 Mt/ year by 2002.

The cast steel production in the integrated facility at Clabecq is 1,2 Mt slabs/year while the rolling has a capacity of 0,5 Mt/year. The EAF facility at La Louvière has an intrinsic capacity of 0,7 Mt slabs/year and the rolling units have a capacity of 1,4 Mt/year. Duferco solves this situation through the transfer of 0,6 Mt of slabs from Clabecq to La Louvière. The new strategy is to manage Clabecq and La Louvière facilities together.

2.5.4. FAFER

Fabrique de Fer de Charleroi (Fafer) is also part of the Usinor group. Usinor announced 50 to 70 million euros (2 billion to 3 billion BF) investments to upgrade the Fafer stainless facilities by 2002. It could increase the local capacity from 0,12 Mt/year to 0,35 Mt/year.

2.5.5. ALZ

ALZ is pursuing an investment programme to increase capacity and product range by the year 2000. ALZ has created a joint venture with the Italian Marcegaglia group for common operating of the hot rolling mill at Stahlwerke Bremen (group Arbed-Sidmar). In this way, ALZ ensures itself of an increased hot rolling capacity and stable supply, necessary to fully carry out its overall investment programme.

2.5.6. Thy-Marcinelle

Thy-Marcinelle was bought by the Italian Riva group from Cockerill Sambre in 1988 and mainly produces wire rod using a 800 kt/year EAF.

2.6. Environmental Perspectives

2.6.1. GHG emissions

The table bellow shows CO2 emissions in the Belgian iron and steel industry by steelshop not taking into account the electricity produced from the off-gases and used internally in integrated steel manufacturing plants, which implies that calculated CO2 emissions for the integrated route are underestimated.

Steelshop	Combustion GJ/t	Electricity KWh/t	Process t CO2/t	CO2 emissions t/t
Coke production	3,7	33	--	0,27 t CO2/t coke
Sinter production	1,5	39	--	0,17 t CO2/t sinter
BF (cowpers)	2,3	65	0,09 t CO2/t pig iron	0,60 t CO2/t pig iron
BOF	0,2	33	0,15 t CO2/t crude steel	0,18 t CO2/t crude steel
EAF	2,1	595	0,05 t CO2/t crude steel	0,34 t CO2/t crude steel
Continuous Casting	0,0	12	--	0,01 t CO2/t cast steel
Ingot Casting	0,4	105	--	0,06 t CO2/t cast steel
Hot Rolling	1,4	105	--	0,13 t CO2/t hot-rolled steel
Cold Rolling	1,0	119	--	0,13 t CO2/t steel

Table 4.- CO2 emissions by steelshop
Source: Econotec and IW

The iron and steel industry is one of the largest energy-consuming industry sectors, accounting for 35 per cent of the global industrial energy consumption in Belgium. In addition to energy consumption, emissions of large quantities of CO2 from steel production, as the inevitable by-product of the reduction of iron ore to pure metal in the blast furnace route, makes the iron and steel industry the most important industrial source of CO2 emissions.

Blast furnaces are predominantly fueled with coal and coke. The specific CO2 emission coefficient of coal considered for Belgium is 95 kg CO2/GJ. CO2 is also emitted during pig iron production because of the decarbonisation of limestone (CaCO3). Limestone is added to the blast furnace charge in order to reduce the impurity content of the iron product. The decarbonisation results in an emission of approximately 0,09 t CO2/t pig iron.

Pig iron from the blast furnace contains 4-5% weight carbon. In the BOF, where pig iron is melted and refined, the carbon content of pig iron is lowered to below 1,9% weight by injecting high-purity oxygen. A chemical reaction occurs, where oxygen reacts with carbon emitting approximately 0,15 t CO2/t crude steel.

The specific CO2 emissions per tonne steel cannot be calculated straightforward from the energy balance of the steel industry because of the significant amount of energy by-products that are produced by the integrated industry as coke oven gas and blast furnace gas. If these gaseous energy carriers are sold, their CO2 emission can either be allocated to the user of the gas (generally a power producer) or to the steel industry. In this study, the emissions related to the use of the off-gases for power production will not be allocated to the steel industry.

In Belgium, national electricity production ranges from nuclear or hydropower plants to coal fired power plants. On average, electricity is produced with a specific CO2 emission of approximately 105 kg CO2/GJ electricity. The CO2 emission coefficient calculated for the electricity produced from the off-gases is approximately 193 kg CO2/GJ. Assuming these reference values, the CO2 emissions per tonne cast BOF-steel (slabs, blooms) are approximately 1.32 t/t and the emissions for one tonne cast EAF-steel (slabs, blooms) are approximately 0.34 t/t.

The CO2 emissions of steel rolling and finishing depend on the product type (sheets, tubes, wire, etc). An average emission for rolling and finishing of 0.35 t/t results in a total emission of 1,67 t/t for the blast furnace route and 0.69 t/t for the EAF route.

2.6.2. GHG emissions mitigation

No feasible economic alternatives to blast furnaces exist today for the bulk of iron production and, therefore, according to the International Iron & Steel Institute (IISI), the ability of the industry to reduce CO2 emissions below the levels achieved over the last 20 years is very limited.

Currently, emission prevention activities in steelmaking are mainly focused on :

- The blast furnace route by the reduction of CO2 emissions, by the development of cokeless ironmaking techniques and by the replacement of this traditional integrated route.

  The former is being followed by changing the method by which coke is added to the blast furnace or by substituting a portion of the coke by other fuels (fuel switch).

  The second is being investigated by looking for means to eliminate the need for cokemaking (cleaner technologies). All over the world, and since many years, steelmakers have been looking for new processes to produce steel through the direct reduction and smelting of iron ores. The ultimate goal of this intensive research was to substitute the traditional blast furnace route, the investment cost of which has made the construction of new plants too expensive. Moreover, the burden preparation, consisting of the coking of coal, and the sintering or pelletising of iron ores, not only requires high capital expenditures, but is also very demanding as to the environmental protection.

  Finally, the conventional EAF process is likely to grow at the expense of BF/BOF capacity in the future (increased energy efficiency).

- The finishing section through casting developments towards more streamlined near-net-shape processes (increased energy efficiency).

IPCC list of improvement options applied to the iron and steel industry

2.6.2.1. Fuel switch

- Blast furnace iron production is based on coal as energy source: Other fuels like oil, natural gas, hydrogen, electricity and plastic waste can be used.

- New and emerging technologies include the injection of coal and natural gas to displace coke such as DRI and smelting reduction (see paragraph 2.6.2.2.).

- Biomass can be converted into charcoal, a product with a similar chemical structure as coke (the Brazilian iron production is currently still to a large extent based on the use of charcoal). But charcoal is not relevant for Belgium.

2.6.2.2. Increased energy efficiency and cleaner technologies

- Smelting reduction

Due to the different reaction conditions and the full integration, the theoretical energy demand of smelt reduction is lower than that of a blast furnace. Previous studies estimated the energy consumption to be 20-30% lower than that of the conventional blast furnace route.

Smelt reduction plants generally have a higher coal input per tonne product than current blast furnaces, but export larger quantities of fuel gas. The exported offgas of the COREX-process has a heating value of approximately 7 MJ/Nm3 (LHV) and is relatively clean (sulphur content of 10-70 ppm). Net energy consumption of smelt reduction is therefore lower than that of the blast furnace route. In the near future, net fuel use is estimated to be 20.4 GJ/tonne pig iron with a net electricity production of 2.1 GJe/tonne (595 kWhe), equal to a net primary energy consumption of 15.1 GJ/tonne (assuming 40% electricity generation efficiency)[3].

In the long term further reductions leading to a net specific energy consumption of 11 GJ/tonne pig iron may be expected. Currently operating plants already show energy consumption levels comparable to the blast furnace routes, but at much smaller scales. The first commercial COREX plant operating in South Africa has a capacity of only 300,000 tonnes/year and shows an estimated net specific energy consumption of 17 GJ/tonne pig iron, which is comparable to that of a modern blast furnace, including ore preparation and coke making. Since the figure is valid for a small first-of-a-kind plant, lower energy consumption figures may be expected in the near future. This improvement can be reached through increased capacities, optimisation of the carbon monoxide/ore-interaction, and optimisation of fuel gas use.

CO2 emissions associated with smelting reduction technologies and comparisons with the emissions from conventional technology (blast furnace) are presented in Table 5.

	Blast furnace	**COREX**	**CCF**
CO2 emissions (t/t hot metal)	**1,7**	**1,3**	**1,2**

Table 5.- CO2 emissions from ironmaking technologies

Smelting processes such as COREX and CCF are technologies that Belgium will use in a time horizon of 15-20 years. Conversely, Sidcomet will operate in Belgium by 2003 with a capacity of 1500 tonnes/year.

- Improvements in the finishing section:

While continuous cast product is being used in a growing number of applications, ingot casting continues to be used world-wide by foundries and specialty producers to produce steel for some specific uses.

In Belgium, continuous casting has almost replaced ingot casting completely and steel is mostly cast into semi-finished products in continuous casting machines. Only less than 1% of Belgian production is cast in ingot form and subsequently rolled into semi-finished forms.

On the other hand, future developments will lead to ultra-thick slab casting for thick plates and direct strip casting for sheets. Thin slab casting and strip casting will further reduce the energy consumption and materials losses in the rolling sections.

In Belgium, the application of thin strip continuous casting technology at an industrial level of operations is foreseen by 2010[11] in its major iron and steel company Cockerill Sambre.

Energy savings can be estimated by comparing the energy required for the slab furnace and the driving energy of the hot strip mill to energy required for the near net shape casting machine. In the direct casting plants, energy used for casting and rolling is reduced to 0.6 GJ/tonne rolled steel (primary energy) equivalent to savings of 75% relative to current best practice using conventional technology[3].

2.6.2.3. Recycling and reuse

The steelmaking and the foundry industries are highly dependent upon the ready availability of scrap from manufacturing operations and from the recovery of products that are no longer used or needed such as old buildings, industrial machinery, discarded cars and consumer durables. The remelting of scrap requires much less energy than the production of iron and steel products from iron ore, but this operation is limited by scrap exports, steel stored in long life products and product quality requirements.

Scrap is used as a supplement in steelmaking but is limited as a major feed material because the supply of high-quality scrap is limited. For this reason, some EAF facilities consume DRI to improve steel quality.

2.6.2.4. Dematerialisation and materials substitution

Light weight design or high quality steel to increase the life of products and product parts.

Recently developed high strength steels can be made 2 or 3 times as strong as the traditional carbon steels. For example, the weight of steel parts, such as the crash resistant beams in car doors, for which strength is a vital property, can be reduced to 1/3 of the value of comparable components in today's conventionally manufactured cars.

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[11] Activities Report of Cockerill Sambre.

2.6.3. Other environmental impacts

Both integrated and non-integrated production facilities emit significant quantities of heavy metals into the atmosphere.

In the integrated route, dust from primary processes may contain several heavy metals such as cadmium, lead, chromium, nickel, zinc, copper and arsenic. Mercury is also emitted from coke plants. Dust from stainless steel production can contain 4-5 per cent nickel and chromium and dust from merchant iron production may contain 20-40 per cent zinc and 3-5 per cent lead. These emissions occur at different stages during storage, handling, crushing, sieving and transport of metal-containing materials.

In the EAF route, as the composition scrap varies according to its origins, the content of the emitted dust changes from plant to plant. In addition, the scrap composition has been shown to influence the oxygen content in the furnace and, subsequently, the formation of volatile organic compounds during the operations. At EAF steel plants, heavy metals and toxic organic substances such as polycyclic-aromatic hydrocarbons (PAH) and dioxins are emitted together with the process gases during the melting of scrap. Toxic metals are either alloy elements like nickel and chromium or contaminating elements like lead, mercury and cadmium. Mercury is emitted mainly in gaseous form. Emissions of heavy metals also occur from the cutting of scrap, from the converters and from casting. The content of metals in dust varies widely according to the type of steel produced.

A rough estimate of a EAF steel plant emissions reported by the Contracting Parties to the Oslo and Paris Commission (OSPARCOM) shows that approximately 15 000 tonnes of dust are emitted per year[12]. The estimate is made assuming dust emission of 0.5 kg/t melted steel. Annual emissions are significant for some metals. Based on a correlation between dust emissions and metal content, emissions from secondary plants have been estimated for both mercury and cadmium as 6 tonnes per year. For lead the amounts were estimated to be 550 tonnes, and for zinc 3 500 tonnes per year.

Approximately 25 per cent of dioxin emissions in 1989 were related to EAF facilities. The emissions of dioxins from these plants within the Contracting Parties to OSPARCOM are estimated to be 0.5 kg/year. Chlorobenzenes and chlorophenols are emitted by steel plants as well.

In both the integrated and non-integrated processes, control devices such as fabric filters, electrostatic precipitators and scrubbers are used to capture and reduce the amount of dust emitted. However, when using these techniques, environmental trade-offs such as the generation of increased quantities of toxic waste need to be considered, e.g. a wet scrubber uses about 3 800 litres of water per tonne of steel. The principal pollutants removed from the waste gas are total suspended solids and metals (mostly zinc and lead). Any further reduction of emissions, however, can only be achieved by using an increased amount of energy, which will result in increased emissions from power stations.

In addition, the iron and steel industry generates large quantities of solid by-products and waste materials. Conventional integrated steel plants produce 500 kg of solid waste per tonne of crude steel whereas EAF plants generate 20 kg/tonne.

Almost 90 per cent of the solid by-product generated in steel production can be recycled, either as recuperated raw materials or as saleable products. Indeed, the slag generated in ironmaking processes is reused extensively in the construction industry. BOF slag can be processed to recover its high metal content for use in sintering or blast furnaces, but its application as saleable construction material is more limited than the blast furnace slag used for road aggregate and cement manufacturing.

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[12] “Environmental Requirements for Industrial Permitting. Case Study on the Iron and Steel Sector.” OECD, 1999.

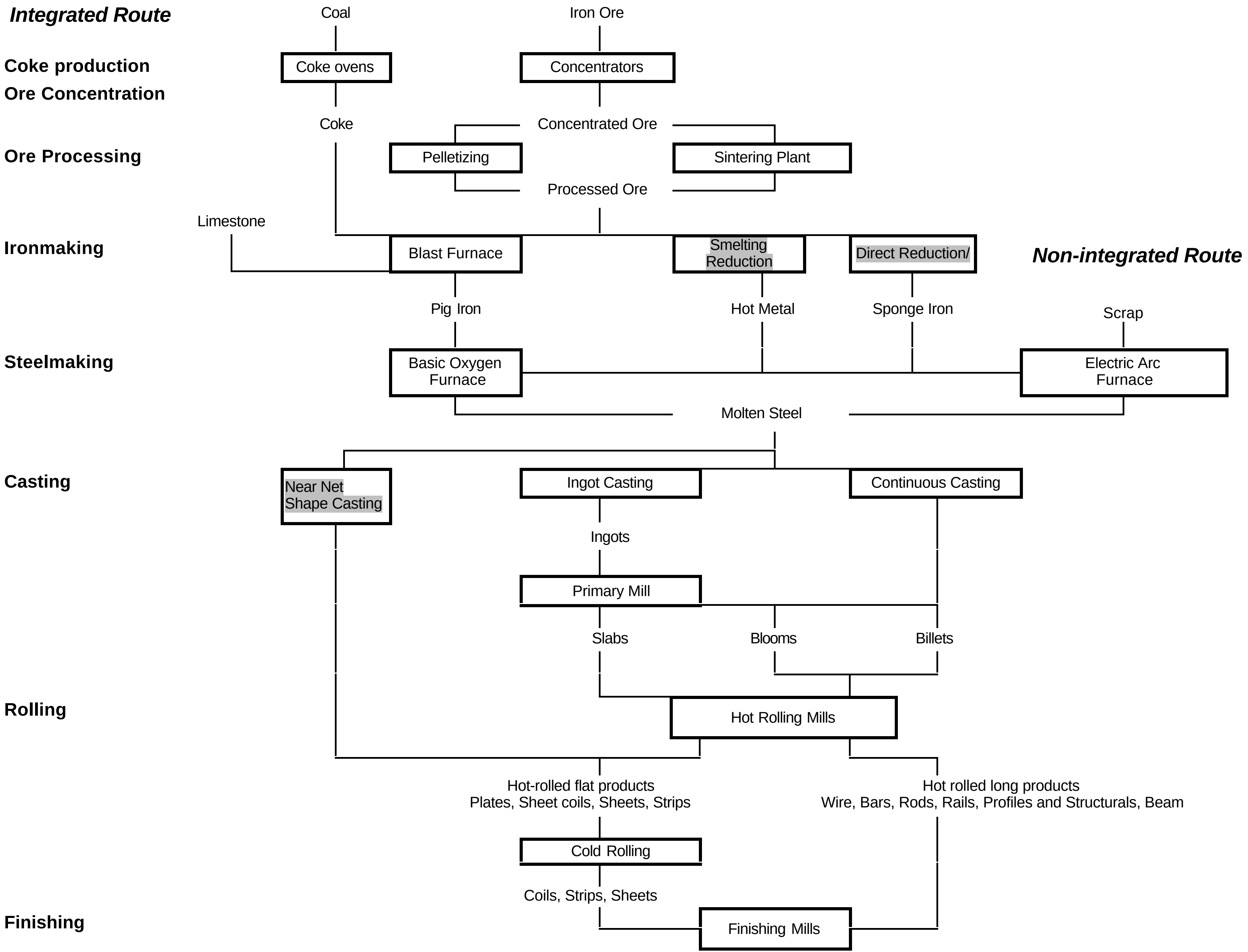


Figure 3.- Basic Flow Diagram of Iron and Steel Manufacturing Process

Coke oven

Material Inputs		*Source*
Coal	1,35 t <> 42,4 GJ	Cockeril Sambre (CS) and PCI conversion
Energy Inputs		
Electricity	0,12 GJ	ECONOTEC and IW
Coke oven gas	3,08 GJ	
BF gas	0,41 GJ	
Vapour	0,18 GJ	
Residual fuel	0,07 GJ	
Material Outputs		
Coke	1 t <> 27,2 GJ	CS and PCI conversion
Coke tar	0,04 t	CS
Ammoniac	0,013 t	CS
Benzol	0,01 t	CS
Naphtha	5,33 E-04 t	CS
Energy outputs		
Coke oven gas	7,9 GJ	IW
	285 Nm3 <> 750000 J hydrogen	CS

Sinter production

Material Inputs		
Iron ore	1 t	MATTER
Energy Inputs		
Electricity	0,14 GJ	ECONOTEC and IW
Coke	1,32 GJ	
Coke oven gas	0,07 GJ	
Residual fuel	0,06 GJ	
Material Outputs		
Sinter	1 t iron equiv.	MATTER

Blast Furnace

Material Inputs		
Coke	0,5 t <> 13,6 GJ	CS and PCI conversion
Iron ore (sinter)	1,6 t	CS
Oxygen	0,1 t	MATTER
Energy Inputs		
Electricity	0,23 GJ	ECONOTEC and IW
BF gas	1,81 GJ	
Coke oven gas	0,18 GJ	
Natural gas	0,18 GJ	
Heavy gas oil	0,09 GJ	
Material Outputs		
Pig iron	1 t	CS
BF slag	0,29 t	National Slag Association
Process emissions		
Direct CO2	0,09 t/t pig iron	ECONOTEC
Energy Outputs		
BF gas	5,43 GJ	IW

BOF

Material Inputs		*Source*
Pig Iron	0,9 t	CS
Steel Scrap	0,22 t	CS
Limestone	0,04 t	CS
Dolomite	0,01 t	CS
Oxygen	50-55 Nm3	CS
Energy Inputs		
Electricity	0,12 GJ	ECONOTEC and IW
Natural gas	0,10 GJ	
Coke oven gas	0,09 GJ	
Residual fuel	0,02 GJ	
Vapour	0,01 GJ	
Coke	0,007 GJ	
Material Outputs		
Crude Steel	1 t	CS
Slag	0,1 t	CS
By- products	0,08 t	CS
Direct CO2	0,15 t/t steel	ECONOTEC

EAF

Material Inputs		
Steel Scrap	1,08 t	CS
Oxygen	0,05 t	MATTER
Energy Inputs		
Electricity	2,14 GJ	ECONOTEC and IW
Natural gas	1,65 GJ	
Coke oven gas	0,23 GJ	
Coal	0,06 GJ	
Vapour	0,06 GJ	
Coke	0,04 GJ	
Heavy gas oil	0,02 GJ	
Material Outputs		
Crude Steel	1 t	CS
Slag	0,08 t	CS
Direct CO2	0,05 t/t steel	ECONOTEC

Continuous Casting

Material Inputs		
Crude Steel	1,03 t	MATTER
Energy Inputs		
Electricity	0,04 GJ	ECONOTEC and IW
Natural Gas	0,025 GJ	
Coke oven gas	0,015 GJ	
Coke	0,0004 GJ	
Material Outputs		
Continuous casting steel	1t	MATTER
Steel Scrap	0,02 t	MATTER

Ingot Casting

Material Inputs		*Source*
Crude Steel	1,2 t?	
Energy Inputs		
Electricity	0,37 GJ	ECONOTEC and IW
Coke oven gas	0,41 GJ	
Material Outputs		
Ingot Casting Steel	1 t	
Steel Scrap	0,2 t	IW

Hot Rolling

Material Input		
Continuous casting steel	1,05 t	MATTER
Energy Input		
Electricity	0,38 GJ	ECONOTEC and IW
Natural gas	0,98 GJ	
Coke oven gas	0,27 GJ	
BF gas	0,09 GJ	
Vapour	0,01 GJ	
Material Output		
Hot rolled steel	1 t	MATTER
Steel Scrap	0,03 t	MATTER

Cold Rolling

Material Inputs		
Hot rolled steel	1,046 t	MATTER
Energy Inputs		
Electricity	0,43 GJ	ECONOTEC and IW
Vapour	0,45 GJ	
Natural gas	0,26 GJ	
BF gas	0,23 GJ	
Residual fuel	0,04 GJ	
Heavy gas oil	0,02 GJ	
Gas oil	0,02 GJ	
Material Outputs		
Cold Rolled Steel	1 t	MATTER
Steel Scrap	0,036 t	MATTER

Table 6.- Material and energy input/output in Belgian iron and steel manufacturing by steelshop

DRI production

Material Inputs			*Source*
Pellets	1,5	t	MATTER
Energy Inputs			
Electricity	0,7	GJ	MATTER
Natural gas	10,8	GJ	MATTER
Material Outputs			
DRI	1	t	MATTER
Direct CO2	0,077	t/t DRI	MATTER

COREX iron production

Material Inputs			
Pellets	1,5	t	MATTER
Oxygen	0,71	t	MATTER
Energy Inputs			
Coal	29	GJ	MATTER
Material Outputs			
Iron	1	t	MATTER
Blast furnace slag	0,45	t	MATTER
Direct CO2	0,15	t/t iron	MATTER
Energy Outputs			
Steam	6,4	GJ	MATTER
Residual gas	10,9	GJ	MATTER

CCF iron production

Material Inputs			
Iron ore	1,5	t	MATTER
Oxygen	0,73	t	MATTER
Energy Inputs			
Coal	20,1	GJ	MATTER
Electricity	0,5	GJ	MATTER
Material Outputs			
Iron	1	t	MATTER
Blast furnace slag	0,35	t	MATTER
Direct CO2	0,077	t/t iron	MATTER
Energy Outputs			
Steam	4,3	GJ	MATTER
Residual gas	4	GJ	MATTER

Table 7.- Material and energy input/output in new and emerging ironmaking technologies

3. THE CEMENT INDUSTRY

3.1. Cement production and consumption in Belgium

Since 1990s, Belgium produces approximately 7 million tonnes of cement per year.

Currently, Belgium produces 6 million tonnes of clinker (from which one million tonnes are exported) to produce 7,5 million tonnes of grey and white cement and consumes 558 kg of cement per inhabitant.

Belgian construction market absorbs approximately 5 million tonnes of cement. Every year Belgium exports 2 million tonnes of cement to three major countries: Netherlands, Germany and France. International trade in cement is limited because of the relatively high cost of transporting a bulky and relatively low-cost product.

In 1998, the cement industry employed 1900 workers. Taking into account the sectors of ready mix concrete, precast concrete and fibre-cement, indirect employment concerning cement industry results in about 12000 workers more.

The three major cement categories are produced in Belgium in the following proportions: 35 per cent of production is Portland cement, 23 per cent is blended Portland cement and 42 per cent blast furnace cement.

Currently, about 62% of the cement produced in Belgium is manufactured using dry process technology and 38% using wet process technology.

3.2. Product characterisation

Construction demands different types of cements for specific conditions and purposes.

Most Portland cement made today is a general-purpose cement. Other specialty cements such as blended Portland cement and blast furnace cement are produced from the same basic raw materials, but vary in chemical composition and physical performance. They are classified on the basis of national standards (BENOR) (see Figure 4).

Portland cement is a finely interground mixture of clinker and 5% gypsum. Portland cement can be produced either by integrated cement plants, which manufacture clinker and grind it to make cement, or by stand-alone facilities that grind clinker obtained elsewhere.

Blended portland cement is a mixture of portland cement (or ground clinker plus gypsum) and chalk or fly ash. In Belgium, two basic types of blended portland cement are recognised, CEM II / A-M where the proportion of the chalk is in the range of 6% to 20% and CEM II / B-M where the proportion of fly ash is in the range of 21% to 35%.

Blast furnace cement is a mixture of portland cement and slag. Three basic types are recognised being the proportion of the slag in the range of 36% to 95%.

Cement is used as a binding agent, most often as a component of mortar (a leaner mixture of cement combined with sand, and in same case lime) for masonry construction for joining bricks and blocks or as a component of concrete (cement combined with aggregate and water).

White cement is a Portland cement containing a minimum of iron oxide or other colouring oxides. Its consistent whiteness and brightness result from the judicious choice of the raw materials making up the clinker base. It is primarily used to manufacture decorative concrete.

The successful use of concrete in structures has come about from the addition of steel reinforcements. Reinforced concrete is now one of the most common materials from which structures (such as buildings and bridges) are built.

Concrete structures are either built in situ or assembled for precast elements in the form of girders, blocks, panels, etc. Concrete breeze blocks and fibre reinforced roofing tiles can substitute for structural fired clay bricks and tiles.

3.3. Main production routes in the cement industry

Cement production plants are typically located near quarries, the source of raw materials. Clinker, the rough precursor to cement, is essentially made from minerals containing calcium, silicon, aluminium and iron. Limestone, marl and chalk are the major sources of calcium. Clay, shale, bauxite and iron ore provide the silicon, aluminium and iron components.

In Belgian cement plants, chalk from quarries provides calcium; the argil which provides silica comes from the quarry overburden; fly ash recovered from power stations contains the required alumina and iron oxide in the form of pyrites is received by barge.

Cement manufacture consists of two essential stages:

1. The manufacture of clinker, obtained from the calcination in high temperature kilns of raw materials.
2. The manufacture of cement as a final product from the blending of clinker and calcium sulphate and other components such as blast furnace slag or fly ash.

Two different processes, "dry" and "wet", are used in the manufacture of clinker.

The first step after quarrying in both processes is crushing. Some cement plants use heavy wheel-type rollers that crush the materials into powder against a rotating table (roller mills). Most of facilities grind the materials in horizontal steel rotary cylinders filled with thousand of steel balls (ball or tube mills). As the mill turns, the balls tumble onto the materials and crush it into powder.

Heated to about 1,400° C in huge cylindrical steel rotary kilns lined with special firebrick, the raw materials chemically combine to create clinker.

In the wet process, the raw materials, properly proportioned, are ground with water, thoroughly mixed and fed into the kiln in the form of a "slurry" (containing 35-40% of water to make it fluid). In the wet process, the slurry can be easily mixed but a large amount of energy is consumed in clinker burning due to water evaporation.

In the dry process, raw materials are ground, mixed and fed to either a preheater or directly to the kiln in a dry state.

Dry and wet process kilns are mounted with the axis inclined slightly from the horizontal. The finely ground raw material or the slurry is fed into the higher end. At the lower end is a roaring blast of flame, produced by precisely controlled burning of powdered coal, oil, natural gas or waste-derived fuels under forced draft. As the materials moves down the progressively hotter kiln, certain elements are driven off in the form of gases. The remaining elements unite to form a new substance with new physical and chemical characteristics, the clinker. Clinker is discharged red-hot from the lower end of the kiln and generally is brought down to handling temperature in various types of coolers. The heated air from the coolers is returned to the kilns or preheaters, a process that saves fuel and increases burning efficiency.

Once cooled, the clinker goes to the finishing mill where it is ground. Cement as a finished product is manufactured by the homogeneous mixture of the ground clinker and calcium sulphate (gypsum) with or without (depending on the type of cement) one or more additional components such as blast furnace slag, fly ash, fillers, etc. The Figure 4 shows the composition and designation of the three different cements produced in Belgium.

Gypsum is added to control the setting time of the cement; it comes mainly from recycled products and it is present in all cements in a proportion of about 5%.

The compounds of *portland cement* are clinker and gypsum. Fly ash and blast furnace slag are secondary industrial products which are used in the *blended Portland cement* and *blast furnace cement* manufacturing, respectively.

Fly ash from thermoelectric plants takes the form of fine powder. It has the property of combining with lime (like natural pozzolana).

Blast furnace slag is a by-product of blast furnaces in steelworks. Similar to clinker, slag has hydraulic power. When delivered to the cement plant, slag has a moisture content of 20%. It must be fully dried before being fed into the blast furnace cement-grinding process.

The premetered mixture is fed to tube mills or roller mills (finishing mills) in which clinker is finely ground together with gypsum, blast furnace slag, fly ash or filler. Finished cement is stored in silos, tested in detail and filled into bags or loaded onto trucks for transportation in bulk.

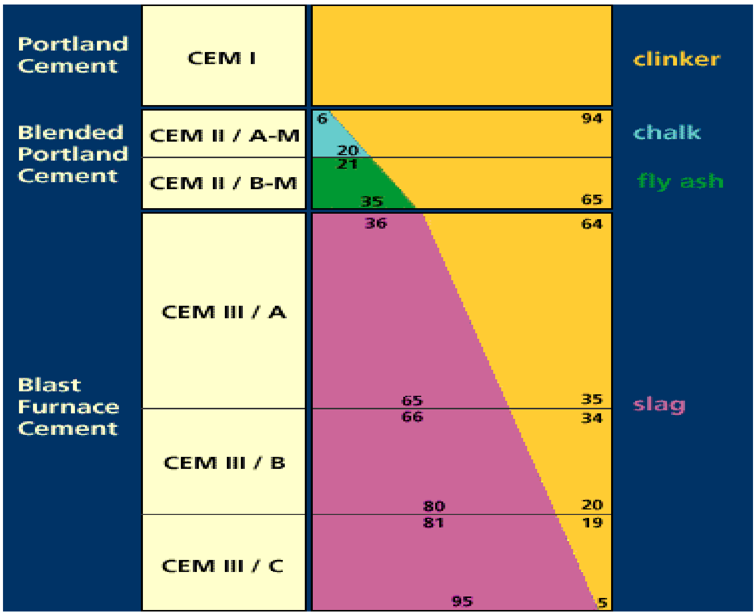


Figure 4.- Cement compositions
Source: FEBELCEM

White cement is a pure white hydraulic binder whose physical properties are equivalent to those of grey cement. The whiteness of the white cement comes from white chalk which is its predominant basic constituent. The aluminium oxide required in the recipe of the clinker is provided by kaolin (china clay), the silica comes from pure argil. Throughout the production process, every precaution is taken to ensure that the clinker is not contaminated by any materials which might alter its colour.

The production of white cement is similar to grey cement apart from the fact that the mills use ceramic balls which are abrasion-resistant to avoid alteration during grinding.

World-wide, cement is manufactured in five kiln types: wet process, dry process, dry process with preheater, dry process with precalciner, and semidry process kilns. The table 8 compares the five different systems. Although all kiln systems have the same three zones (drying and preheating zone, calcining zone and sintering or burning zone), there are differences in the types of processes used.

The same raw materials are used in wet and dry process kilns, however, the moisture content and processing techniques differ, as do the kiln designs. Wet process kilns must be longer in order to dry the wet mix, or slurry, which is fed into the kiln. Dry process kilns produce high temperature exit gases which can be use to generate electrical power. Preheater, precalciner, and semidry process kilns are less common devices, and differ from wet and dry process kilns in terms of kiln length, process inputs, operating temperature, fuel efficiency, and other factors.

In Belgium, cement is manufactured using the wet process, the dry process and the dry process with precalciner.

Kiln type	**Description**	**Advantages**	**Disadvantages**	**Energy requirement (GJ/t clinker)**
Wet process	Water is added during grinding of raw materials to make a slurry that is 30-40% water. A longer kiln than other process types is needed in order to dry raw materials.	Reduces the amount of cement kiln dust produced.	High energy input needed	5,0 to 7,5
Dry Process	Dry raw mix is pneumatically pumped to the top of the kiln. Hot gas from the dry process kiln can be used to generate energy.	Requires less energy input than the wet process kiln.	-------	3,6 to 4,5
Dry Process with Preheater	The preheater heats and partially calcines raw feed before it enters the kiln. It uses a four-stage heat exchange cyclone system.	Raw material is more evenly calcined	-------	3,1 to 3,5
Dry Process with Precalciner	Similar to the preheater except there is a secondary firing system (flash furnace) attached to the lower stage of the preheater tower.	Increases output and operational life, decrease heat load and operation costs.	-------	3,0 to 3,2
Semidry Process ("grate process" or "lepol" kiln)	Raw feed consists of pellets with moisture content of 10-15%. The pellets are dried and partially calcined on a moving grate preheater before entering the kiln	Better suited for moist climates	Low output, more labour-intensive than other processes.	3,2 to 3,9

Table 8.- Kiln types in cement manufacturing
Source: US EPA and CEMBUREAU

The figure 4 gives a general overview of the steps involved in the main cement manufacturing routes.

Concrete

Concrete is formed by mixing hydraulic cement, water, aggregate materials (sand, gravel, or crushed stone) and water. The distribution of the aggregate particle sizes and the relative proportion of cement, aggregate, and water determine the workability and durability of concrete. The most important variables affecting the strength of concrete at a given age are the water/cement ratio and the degree of compaction. Typical proportions of materials used in concrete production are as follows: 11% cement, 16% water, 6% air, 26% fine aggregates and 41% coarse aggregates. In weight, 0.6 tonnes of sand, 1.4 tonnes of gravel, approximately 0.3 tonnes of cement and 150 liters of water are required to produce one cubic meter of concrete[13].

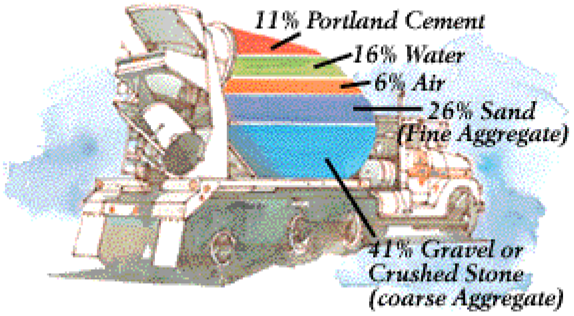
From the cement production plants, most cement is shipped to ready mix concrete producers. At concrete batching plants, the cement is elevated to storage silos pneumatically or by bucket elevator. The sand and coarse aggregate are transferred to elevated bins by front-end loader, crane, conveyor belt, or bucket elevator. From these elevated bins, the cement and aggregate are fed by gravity or screw conveyor to weigh hoppers which combine the proper amounts of each material. Just a small amount of cement is needed to create concrete.

Concrete batching plants then store, convey, measure, and discharge the ready-mix concrete into trucks for transport to construction sites.

When stone, sand, water, and cement are mixed together in the proper proportions, the water and cement form a paste that coats every stone and grain of sand and fills the spaces between them. The water triggers a chemical reaction called hydration. The reaction of hydration itself releases heat-a boon in winter construction. This reaction forms a gel which, as it hardens, binds the stones and sand into a solid mass that becomes stronger and stronger.

The cement's rate of hydration determines the setting and hardening time of the concrete. The initial reaction must be slow enough to permit workers to place and finish the concrete in its plastic state. Once in place, however, the concrete is allowed to harden into its finished form.

Concrete components: Cement is the key ingredient of concrete, but makes up just 11% of the mix.



The rate of hardening can be precisely controlled. The gypsum ground into cement at the plant regulates setting time. Different types of cement have different setting times, and concrete additives are available to speed or slow setting. Temperature also affects setting time.

Although most strength development occurs in the first few days, concrete can gain additional strength for years if moisture is present and cement hydration is sustained.

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[13] Environmental Report HCB 3Holderbank" Cement and Concrete with data for the period 1996-1998.

Manufacturers utilise different combinations of cements and aggregates to produce grades of concrete which vary in terms of cost, strength, durability, and rigidity.

Concrete is a material produced and used locally, the transportation distance between building site and concrete plant in Belgium is, on average, 150 km (source: CCB).

In residential construction concrete is used primarily for foundations. In larger complexes it is used more extensively in walls, floor and roof slabs because of its strength and non-combustibility.

Cellular Concrete

Autoclaved cellular concrete has been used in Europe since 1914. Cellular concrete is made of lime as well as cement, sand and water. After these components have been homogenised, aluminium powder is added, which acts as a gas-forming, raising agent, producing a frothy mass which is cut with wires and hardened in autoclaves. A chemical reaction produces hydrogen bubbles resulting in the expansion of the mass and a lightweight concrete block. The concrete blocks are then steam cured to stabilise the cellular structure. The end product has a fifth of the density and one tenth of compressive strength of conventional concrete. Its application is restricted to load bearing walls in low rises, and partition and curtain walls in high rises. Cellular concrete facilitates construction and offers optimum thermal insulation.

3.4. Technological Perspectives

A considerable amount of energy is required to bring raw materials up to the clinkering process temperature of about 1,450°C in the kilns. Reducing energy consumption is a top priority in order to keep cement works competitive.

The cement industry's technological evolution, in its efforts for higher productivity, is reflected in an increasingly efficient use of resources such as raw materials and fuels. Since 1960, specific fuel consumption in cement kilns has been cut almost in half (see paragraph 3.6.1.).

3.4.1. Growth of dry-process

The cement industry has boosted efficiency by concentrating new capital investment in plants that use the dry process of cement manufacture and by phasing out operations that rely on the more energy-intensive wet process. These processes are selected with consideration given to properties of raw materials, costs of fuel, conditions of location and others. For the wet process, plant construction cost is rather low and high quality products are manufactured easily. On the other hand, the dry process consumes less energy and its running cost is lower[14]. The progress of technology is, however, eliminating the differences in quality between products from the above processes, while needs for energy conservation are getting increasingly strong. In future, the wet process will not be employed positively.

To save energy:

- Modern cement plants preheat the materials before they enter the kiln. The preheater tower supports a series of vertical cyclone chambers through which the raw meal passes one its way to the kiln. Hot exit gases rising from the kiln heat the material as it swirls through the cyclones.

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[14] “Cement Industry”. Handy Manual. UNIDO, 1994.

- Some preheaters contain a furnace or precalciner at the bottom of the preheater tower just before the kiln. Material from the last stage cyclone enters the precalciner along with hot combustion air and fuel. As much as 95% of calcination - the removal of carbon dioxide from raw materials - takes place here.

Kiln systems with 5 or 6 stage cyclone preheater and porecalciner are considered standard technology for new plants today as the extra cyclone stages improve thermal efficiency.

3.4.2. Grinding process

The process in the kiln is the most energy intensive. However, the production of powders, either from the raw materials before the process in the kiln or from the product from the kiln is also important in the building materials sector. Mixing, grinding and milling machines are the major electricity consumers in this sector. The currently used grinding and milling machines are tube (ball) mills (open or closed circuit) and roller mills (vertical or horizontal), which are very energy inefficient.

Over 95% of the energy input to the machines ends up as waste heat, whereas only 1 to 2% of the input power is used to create new surface (the objective of grinding and milling). After milling, separators (classifiers) are used to distinguish between particles that are fine enough and coarse particles that have to be recycled to the mill for a second comminution. However, conventional classifiers typically recycle as much as 60% of product-quality fines back to the mill. This results in over-grinding, which increases energy use.

The cement grinding process, in particular, requires a large amount of electrical energy. The constant demand for ever finer cements leads to higher specific electricity consumption. Also, the impact of the balls in the traditional ball grinders causes energy loss in the form of heat. Tube mills (where the material is ground by impact and friction of steel balls) have a throughput capacity of up to 400 t/h and a specific energy requirement of 12-16 kWh/t. Roller mills (in which the grist is comminuted on a rotating pan by rollers) require less energy (10-14 kWh/t) at the same capacity as tube mills, but they are of limited use for very abrasive materials. Work is currently underway to improve this situation[15].

Currently the raw materials in cement production are ground using ball mills in most of facilities, while high pressure processes are not yet used much in Belgium.

On average, in the European Union grinding of raw materials uses approximately 16-22 kWh/tonne. Final product (cement) grinding technology is reasonably efficient with 80% of the capacity being ball mills (high efficiency or with a separator), although the most efficient process on the market (combined roller press and ball mill) was only applied for 5% of the capacity.

The electricity consumption of finished Portland cement (depending strongly on fineness material) is estimated at 28-55 kWh/tonne. Additives are ground as well and consume approximately 52 kWh/tonne[16].

The combined roller press and ball mill technology is at the demonstration and market introduction phase in the European Union. It is expected that full deployment will only come when major plant refurbishment is undertaken. This is generally done over a 20 year lifetime. Even in these circumstances 100% penetration is not expected but rather about 60 - 70 %. The actual deployment in the European Union is at about 7 - 10 sites. However it is estimated that about 200 plants could benefit from the technology.

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[15] CBR

[16] ATLAS Project.

3.5. Current and future technology and capacity

In Belgium cement is produced in 5 plants of which 3 are grinding plants without kilns.

The cement production capacity in Belgium in 1996 was 9,74 million of tonnes and in 1998 was 10 million of tonnes (source: Cembureau).

Table 9 presents the expected evolution of production capacity in the Belgian cement industry estimated from the investments plans of major facilities (synthesised bellow).

	1995	2000	2005	2010
Capacity (million tonnes)	10	10	11	11

Table 9.- Cement production capacity

In the context of capacity evolution account, two factors concerning particular nature of cement manufacture have to be considered: its long term largely unchanging product and manufacturing process and its very slow rate of obsolescence.

The cement industry is a capital intensive industry. The cost of cement plants is usually above 150 M ECU[17] per million tonnes of annual capacity, with correspondingly high costs for modifications. The cost of a new cement plant is equivalent to around 3 years of turnover. Long time periods are therefore needed before investments can be recovered, and plant modifications have to be carefully planned and must take into account the long-term nature of the industry.

3.5.1. CBR

CBR Cement Belgium uses two types of kiln for burning the raw clinker mix : the dry process and the wet process kiln. CBR Cement Belgium produced 2,9 million tonnes in 1998. It is the only white cement producer in the Benelux countries.

CBR operates quarries of various geological formations: the factory at Lixhe is supplied by a chalk quarry and a marl quarry, it produces clinker and cement; the factory at Antoing is supplied by a hard limestone deposit, it produces clinker for the cement plants at Gent and Mons and for the Netherlands and the outstanding purity of Harmignies chalk allows for the production of white cement.

In 1995, CBR inaugurated a grinding plant featuring a new design: grinding by rolling. In this system, the traditional ball mill is replaced by a roller press. The materials to be milled pass between two rollers turning in opposite directions, while being subjected to very high pressure. Next, the material is processed by the separator which returns particles which have not been ground to the desired fineness for running through the press again. Compared to the traditional mill, the roller system achieves much more favourable power efficiency. The temperature of the cement is lower, which is undoubtedly a benefit for users during the summer period. This new grinding plant (installed at Lixhe and called Grinding I), is based on the principle of grinding a layer of material at high pressure. The roller press allows a saving in electrical energy that is estimated to be between 33 and 51%, depending on the type of cement and the required level of fineness. Heat loss is also lower with this type of grinding mill than with the traditional ball mills.

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[17] CEMBUREAU

In September 1998, CBR announced an investment plan of 0,11 milliards euros (4,5 milliards BF) in a time horizon of 4 years consisting in:

- 0,07 milliards euro (2,7 milliards BF) to stop wet kiln and to increase dry kiln capacity in 300000 tonnes more at Lixhe.
- 0,04 milliards euros (1,8 milliards BF) to stop crushing operations at Mons and to increase twice the capacity of finishing mills at Gent.

3.5.2. CCB

CCB produces cement in its manufacturing plant at Gaurain-Ramecroix using the dry process with precalciner. It has a production capacity of 2 million tonnes of clinker (one of the greatest capacities of Europe). CCB operates in Belgium the biggest quarry of Europe (100 ha and 250 m depth) to obtain raw materials used to produce 2,5 million tonnes of cement and 5 million tonnes of granulates.

CCB operates another quarry at Soignies to produce granulates and possesses several centres of ready mix concrete.

3.5.3. Ciments d'Obourg

Ciments d'Obourg produced 1,6 million tonnes of cement in 1998 using the wet process technology.

3.6. Environmental Perspectives

3.6.1. Natural resources and fuel consumption

The manufacture of cement requires a large amount of clinker, which itself uses many tonnes of raw materials and fuels.

Some of the raw materials used for clinker production are extracted from quarries : limestone materials (chalk, limestone, marl) and silica (loam and clay). Other materials are incorporated in the raw clinker mix : silica (other than loam and clay), alumina, and iron oxide. Part of these materials can be replaced by the so-called **substitution raw materials** produced by other industries, with a corresponding reduction in the energy required for its production.

- Blast furnace slag : A by-product of the manufacture of cast iron, blast furnace slag also possesses hydraulic properties similar to those of clinker. Blast furnace cements also have good resistance to aggressive agents and are immune from Alkali-Silica reaction.
- Fly ash : Produced by the combustion of coal in electricity power stations, fly ash, which contains silica and alumina, assists the setting of hydraulic compounds and thus the hardening of the cement.
- Fuel ash: A by-product resulting from the combustion of coal in the main burner or at the precalciner which contains silica and alumina.
- Filter dust : This dust is recovered from the electrostatic filters of the furnaces of wet process kilns and reused in the manufacture of cement.
- Gypsum : A by-product of the production of phosphoric or citric acid, artificial gypsum slows the hydration reaction of cement. They are referred to as « setting regulators ».
- Ferrous materials: They are produced by the steel-making and chemical industries and contain iron oxides.

- Foundry sands: Resulting from the casting of metal parts, they are used as a source of silica that replaces loam in the dry process kiln.
- Tyres : Sorted from used car and lorry tyres, they are used as a source of iron.

In order to limit the amount of raw materials extracted, cement industry add a significant amount of substitution raw materials to the raw clinker mixture, with a corresponding reduction in dumped waste. In addition, the use of substitution raw materials for the production of cement leads to an equivalent reduction in the volume of clinker, and a consequent reduction in the emissions related to that volume. The evolution of the use of substitution raw materials in the Belgian industry is shown in the table 10.

Year	Portland Cement (%)	Blended Portland Cement (%)	Blast Furnace Cement (%)	t clinker/t ground cement
1980	**65**	**----**	**35**	**0,734**
1982	**51**	**9**	**40**	**0,710**
1985	**33**	**22**	**45**	**0,697**
1990	**41**	**20**	**39**	**0,708**
1995	**35**	**23**	**42**	**0,686**

Table 10.- Reduction of clinker in the Belgian cement production
Source: FEBELCEM

The burning of the mix in the (wet or dry process) kiln at very high temperature requires a large amount of fossil fuels (mainly crushed dried coal). Traditionally, manufacturers have relied on fossil fuels to meet the high energy requirements. However, hazardous waste fuels and solid waste fuels are now being used in addition to fossil fuels to fire the kiln. Cement industry replaces therefore a part of the fossil fuel with **substitution fuels** (which are also stored in covered sheds to limit the spread of dust).

Belgian cement industry uses the following substitution fuels:

- Resofuel : preparation produced in a specialist centre using fuel residues and absorbent materials (mainly sawdust).
- Shredder residues : plastics, rubber, etc., from used cars.
- Low-chlorine plastics : industrial waste, essentially polyethylene.
- Tyres : rubber from used car and lorry tyres.
- Textiles : carpet waste made into pellets.
- Sawdust : from industrial saw mills.
- Others : paper mill slurry, diatomaceous earth used to filter cooking oils, etc.

The rotary cement kiln provides the high temperatures and long burning time needed to completely destroy hazardous wastes. The organic substances which enter the kiln from the flame side remain there much longer than the two seconds at 850 °C normally specified in European legislation for waste incineration. Indeed clinkerisation takes place at 1.450°C, when the white-hot flame reaches 1870 °C. The dwell time of the gases at a temperature of 1.100°C for its part is never less than 5 seconds. If the fuel contains chlorine or sulphur, acid gases are formed, while the use of raw materials (even natural ones) leads to the presence of heavy metals in the process. The reverse flow operation of the kilns together with the long contact time (several hours) between the gases and the alkaline raw materials introduced result in the good capture and neutralisation of the acid gases and heavy metals in the clinker. Thus inorganic compounds such as metals become locked into cement crystalline structure.

Waste fuel burning does not affect the quality of the cement. In fact, some waste products can be processed as raw materials if they contain essential elements for cement. The rubber in scrap tyres, for example, is completely consumed as fuel, and the steel belts provide iron, one of the essential ingredients of cement.

Alternative fuels may require specific treatment. Gaseous, liquid and pulverised or fine crushed solid fuels can be fed to the kiln system similarly to the fossil fuels. Coarsely shredded or even bulky materials can be fed to the preheater/precalciner section or, rarely, to the midkiln section only. For process reasons, the contribution of bulky fuels to the total heat consumption should be limited to about 15 to 30% depending on the kiln system.

Alternative fuels are frequently prepared and blended outside the cement plant by specialised companies in facilities specifically designed for this purpose. The cement plant has to provide the storage and feeding systems only on site.

The table 11 bellow shows the evolution of the use of substitution fuels in the Belgian industry.

Year	**1980**	**1985**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
Fossil fuels	65	51	66	60	56	47	39	36
Recovered fuels[1]	35	45	26	29	33	40	43	45
Waste fuels	0	4	8	10	12	13	18	19

Table 11.- Evolution of the fuel consumption in Belgian cement industry in %
Source: FEBELCEM

[1] Recovered fuels: Slate coal, coal sludge, petrol coke, etc.

3.6.2. GHG emissions

The carbon dioxide (CO2) associated with cement production comes from three sources. These are, in decreasing order of importance:

- clinker production through the calcination/decarbonation process of limestone within the kiln and through the combustion of fossil fuels to maintain the required kiln temperature,
- electricity production for grinding the raw materials and cement, preparation of slurry, for preparation of fuels, for dryers, kilns, fans, coolers, etc,
- the transport of raw materials and fuels.

Over 56% of CO2 emissions result from the decarbonation of raw materials, a factor that is linked to the complex chemistry of the material, to which no change is technically possible. Almost 39% are due to the use of fossil fuels. Emissions due to transport and electricity consumption account for barely 5% of the total.

Clinker contains approximately 65% CaO. The bulk of the CO2 emissions in cement production is therefore not only related to the consumption of fossil energy but a process emission is caused by the calcination/decarbonation of limestone or other calcareous material. This calcining process thermally decomposes CaCO3 to CaO and CO2. The amount of CO2 released in the calcining process is about 550 kilograms per tonne of portland cement produced.

Thus, releases from the cement kilns come primarily from the chemical reaction of the raw materials and secondarily form the combustion of fuels.

In Belgium, national electricity production ranges from nuclear or hydropower plants to coal fired power plants. On average, electricity is produced with a specific CO2 emission of approximately 105,3 kg CO2/GJ electricity (an average electricity of which 38% is produced from fossil fuels). With such a reference value, the CO2 emissions per tonne clinker are approximately 1,07 t/t for the wet process, 0,87 t/t for the dry process and 0,85 t/t for the dry process with precalciner and the CO2 emissions per tonne of cement are approximately 0,018 t/t for portland cement production, 0,016 t/t for blended portland cement production and 0,027 t/t for blast furnace cement production.

The table 12 presents CO2 emissions by clinker manufacturing process and type of cement manufacturing. On average, most of CO2 emissions are due to clinker production (97%) while the transformation of clinker into cement generates only a tiny part of these emissions (3%).

Manufacturing	**Combustion GJ/t**	**Electricity KWh/t**	**Process t CO2/t clinker**	**CO2 emissions t/t**
Wet process clinker production	5,6	55	0,55	1,07 t CO2/t clinker
Dry process clinker production	3,3	70	0,55	0,87 t CO2/t clinker
Dry process with precalciner clinker production	3,0	74	0,55	0,85 t CO2/t clinker
Portland Cement	--	49	--	0,02 t CO2/t cement
Blended Portland Cement	--	43	--	0,02 t CO2/t cement
Blast Furnace Cement	--	71	--	0,03 t CO2/t cement

Table 12.- CO2 emissions by manufacturing process
Source: Econotec and IW

A total of 0.83 tonne of CO2 is emitted per tonne of finished product (80% clinker), and is made up as follows: CO2 form decarbonation is 0.45 tonne per tonne of cement; CO2 from the combustion of fossil fuels is 0.28 tonne per tonne of cement and electricity produced in coal fired power plants to operate on-site installations contribute a further 0.1 tonne of CO2 per tonne of cement.

The overall emissions of CO2 have been falling since 1980 in the Belgian cement industry. As shown in table 13, this result is due to the efforts made to reduce its energy consumption mainly through conversion of wet process kilns to dry process ones.

Year	**1980**	**1985**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
GJ/t clinker	5,9	5,4	4,9	4,8	4,8	4,7	4,8	4,7

Table 13.- Evolution of the energy consumption in the Belgian cement industry
Source: FEBELCEM

3.6.3. GHG emissions mitigation

IPCC list of improvement options applied to the cement industry:

There are a number of ways in which the greenhouse gas “intensity” of cement could be reduced. Essentially, cement producers have three possible means of reducing CO2 emissions: the technology of the clinker kiln, the type of fuel used in the manufacturing process (e;g; coal, oil or solid waste) and the composition of the cement produced (but not all cement types are suitable for all applications, and some cement types are more energy-intensive to produce than others). Other factors that affect the energy and/or GHG intensity of cement production include the physical and chemical properties of the raw materials used and the GHG intensity of electricity used.

3.6.3.1. Fuel switch

Main fossil fuels (“primary fuels”) in the cement industry are coal, petcoke, heavy oil, and, to a lesser extent, natural gas. Non fossil “alternative” fuels derived from industrial sources such as tyres, waste oil, plastics, solvents and many more are commonly used as substitute fuels today.

CO2 emissions depend not only on the amount of fossil energy used, but also on the relative abundance of carbon and hydrogen they contain. Therefore, replacing coal (which has a high specific level of CO2 emission of 107 kg/GJ) with other fossil fuels such as natural gas (which has a lower specific CO2 emission value of 56 kg/GJ) or with alternative fuels allows to reduce the emissions of CO2.

3.6.3.2. Increased energy efficiency and cleaner technologies

CO2 emissions can be reduced by minimising the energy needed for:

- clinker formation by enhancing the energy efficiency of cement kilns and by process conversion away from less energy efficient processes to dry processes.
- grinding by modernising machinery to reduce electricity consumption.

The dry process requires less energy to produce a given amount of clinker. The CO2 emissions resulting from the activity of a wet process kiln using only coal are of the order of 1220 kg CO2/t clinker, while those of a dry process kiln are only of the order of 910 kg CO2/t clinker. On average, for an equal volume of production, wet process kilns emit 30% more CO2 than dry process kilns.

In addition to the dry process, in the last decades the pre-calcination technology has been introduced as energy saving measure in Europe. Another energy saving measure is an increased number of preheaters.

Concerning the grinding process, a roller press allows a saving of electricity (and CO2) that is estimated, depending on the type of cement produced, to be between 33 and 51% compared to a traditional ball mill.

3.6.3.3. Recycling and reuse

A high proportion of conventional demolition waste, and particularly the fraction derived from concrete, bricks and tiles, is well suited to being crushed and recycled as a substitute for newly quarried (primary) aggregates in certain lower grade applications, most notably engineering fill and road sub-base. This practice has been common (though not necessarily widespread) in several european countries for many years. The use of such construction and demolition wastes-derived aggregates in new concrete is much less common, and technically much more demanding.

3.6.3.4. Dematerialization and materials substitution

CO2 emissions can be reduced by:

- optimising the composition of cement (materials substitution);
- improved products (dematerialization).

Limiting non energy-related emissions, i.e. process CO2 emissions from clinker production would be difficult as these emissions are an inherent part of the decarbonisation of limestone (CaCO3) to lime (CaO) during the formation of clinker. However, process CO2 emissions could be significantly reduced per ton of cement produced by blending clinker with an increased proportion of additives (e.g. fly-ash and blast furnace slag) in cement, i.e. by reducing the proportion of clinker in cement.

Concerning materials substitution, limestone can be replaced by other resources such as:

- Fly-ash cement (limited by the availability of fly-ash in a future situation where coal will be replaced by gas or renewables for power production as a result of CO2 reduction policies),
- Blast furnace cement (the introduction of new iron processes like direct reduced iron production and the growth of the electric-arc-furnace route with the decommissioning of a number of blast furnaces, may reduce the slag availability),
- Two types of activated slag cement, based on synthetic slag, fly ash, quicklime and water glass (sodium silicate and potassium silicate).
- Geopolymeric cement based on the use of Na2O and K2O (one tonne of Na2O can produce 5-10 times as much cement as one tonne of CaO because three dimensional geopolymeric silico-aluminate structures are formed, but the application potential is limited as the pH stability of this type of cement is lower and a high pH value is important in situations where steel reinforcements are used, because steel is protected against oxydation in a basic environment).
- Quicklime and pozzolanic mixtures without cement clinker pose also an important alternative (they are currently widely applied in Germany and Italy, but the resulting concrete quality is water sensitive).

Using blast furnace slag, power station fly ash, natural pozzolana or limestone as a constituent of the final cement reduces the clinker required per tonne of cement. This means lower energy-related CO2 emissions and also lower process CO2 emissions.

In Belgium, as shown in the paragraph 3.6.1., part of the clinker is being replaced with alternative materials such as fly ash or blast furnace slag.

The manufacture of blended portland cement, in which part of the clinker has been replaced with fly ash, allows a reduction in CO2 emissions.

The manufacture of blast furnace cement, which contains a much lower proportion of clinker, allows a further reduction in CO2 emissions: The production of one tonne of portland cement (average between white and grey) requires 850 kg of clinker on average, compared to only 430 kg for the same amount of blast furnace cement. The emissions resulting from the production of blast furnace cement are therefore approximately half that those resulting from the production of portland cement.

However, as mentioned above, an ongoing increase in the reutilization of by-products generated by other activities depends on the availability of these substitution materials (fly ash from coal-fired power stations and blast furnace slag from integrated steelshops).

Regarding dematerialization, materials savings are possible using prefabricated concrete instead of precast concrete as prefabricated production of concrete elements allows a better control of the spread in average strength and the design strength is higher with the same water/cement ratio.

Finally, increased strength performance can led to more efficient use of cement. High strength cement/concrete can contribute to a weight reduction of concrete elements, but this is an option that will require a long time for implementation as it is limited by the technological feasibility, the adjustment of building standards and the adjustment of the building practice.

3.6.4. Other environmental impacts

Like all high temperature combustion processes, cement kilns discharge waste materials into the atmosphere : nitrogen oxides, sulphur oxides, heavy metals and organic compounds, as well as dust.

The largest emission source within cement plants is the kiln operation, which includes the feed system, the fuel firing system, and the clinker cooling and hauling system. The kiln generates nitrogen oxides, sulphur oxides, carbon monoxide, and hydrocarbons as part of the normal combustion of fuel used to supply heat for cement kilns and drying operations. Cement kilns also emit particulate matter, trace metals, and certain organic compounds.

Because of intensive solid material handling, the cement industry's main environmental concern is dust emission.

Sources of particulate emissions include raw material storage, grinding and blending, clinker production, finish grinding, and packaging.

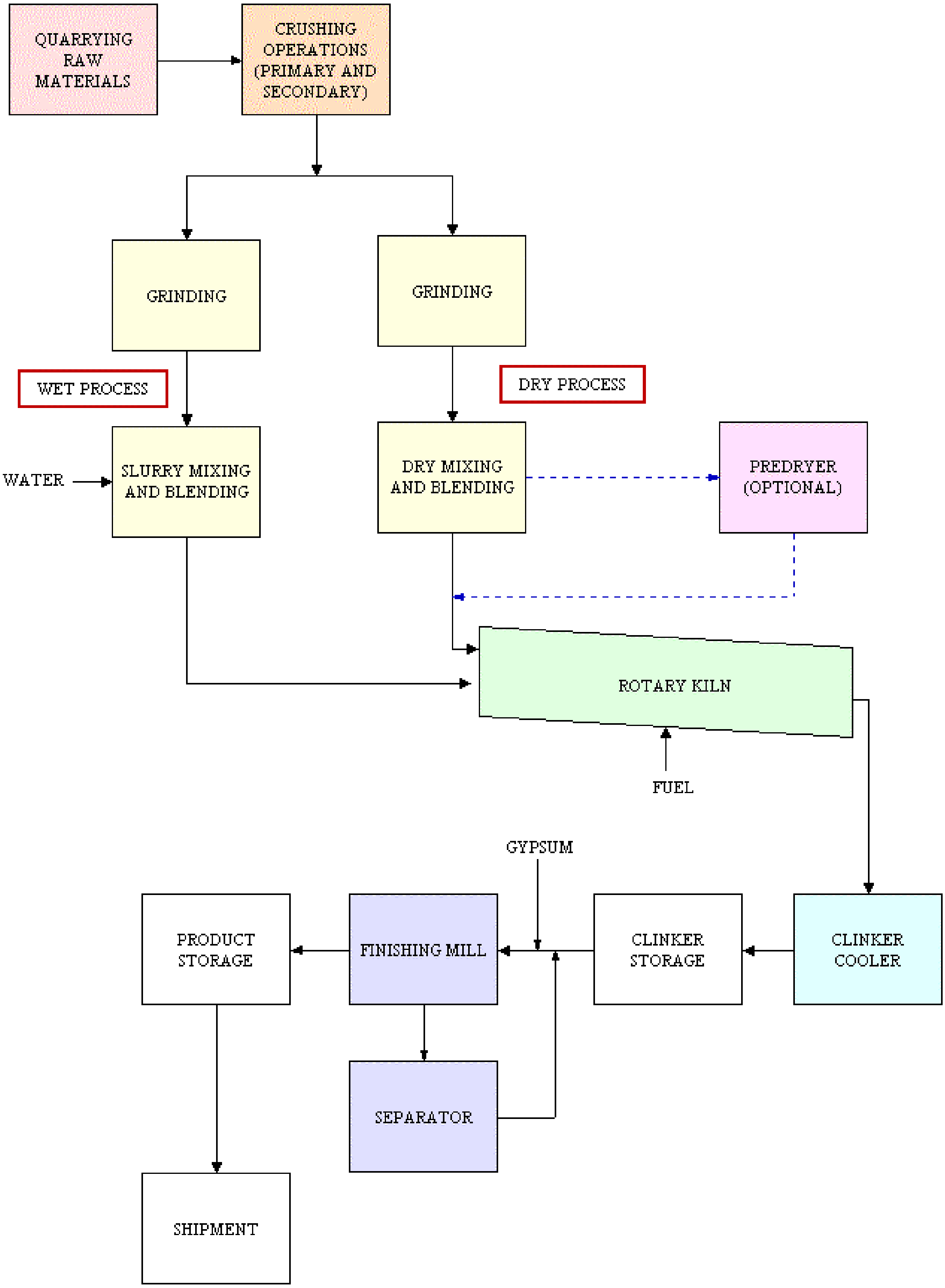

Figure 5.- Basic Flow Diagram of Cement Manufacturing Process
Source: US EPA

Cement clinker wet process

Energy Inputs		*Source*
Electricity	0,20 GJ	ECONOTEC and IW
Coal	1,96 GJ	ECONOTEC and IW
Petrol coke	1,51 GJ	ECONOTEC and IW
Recovered fuels	1,46 GJ	ECONOTEC and IW
Heavy gas oil	0,22 GJ	ECONOTEC and IW
Waste dump	0,23 GJ	ECONOTEC and IW
Natural gas	0,11 GJ	ECONOTEC and IW
Gas oil	0,05 GJ	ECONOTEC and IW
Coke	0,06 GJ	ECONOTEC and IW
Material Outputs		
Portland cement clinker	1 t	ECONOTEC and IW
Emissions		
Direct carbon dioxide	0,55 t	ECONOTEC and IW

Cement clinker dry process

Energy Inputs		
Electricity	0,25 GJ	ECONOTEC and IW
Coal	1,35 GJ	ECONOTEC and IW
Petrol coke	1,06 GJ	ECONOTEC and IW
Recovered fuels	0,50 GJ	ECONOTEC and IW
Heavy gas oil	0,13 GJ	ECONOTEC and IW
Waste dump	0,17 GJ	ECONOTEC and IW
Natural gas	0,07 GJ	ECONOTEC and IW
Gas oil	0,03 GJ	ECONOTEC and IW
Coke	0,03 GJ	ECONOTEC and IW
Material Outputs		
Portland cement clinker	1 t	ECONOTEC and IW
Emissions		
Direct carbon dioxide	0,55 t	ECONOTEC and IW

Cement clinker dry process with precalciner

Energy Inputs		
Electricity	0,27 GJ	ECONOTEC and IW
Coal	1,23 GJ	ECONOTEC and IW
Petrol coke	0,96 GJ	ECONOTEC and IW
Recovered fuels	0,45 GJ	ECONOTEC and IW
Heavy gas oil	0,12 GJ	ECONOTEC and IW
Waste dump	0,15 GJ	ECONOTEC and IW
Natural gas	0,06 GJ	ECONOTEC and IW
Gas oil	0,03 GJ	ECONOTEC and IW
Coke	0,03 GJ	ECONOTEC and IW
Material Outputs		
Portland cement clinker	1 t	ECONOTEC and IW
Emissions		
Direct carbon dioxide	0,55 t	ECONOTEC and IW

Portland cement production

Material Inputs		*Source*
Portland cement clinker	0,95 t	FEBELCEM
Gypsum	0,05 t	FEBELCEM
Energy Inputs		
Electricity	0,18 GJ	ECONOTEC and IW
Material Outputs		
Portland cement	1 t	ECONOTEC and IW

Blended Portland (Fly ash) cement production

Material Inputs		
Portland cement clinker	0,75 t	MATTER
Fly ash	0,25 t	MATTER
Energy Inputs		
Electricity	0,15 GJ	ECONOTEC and IW
Material Outputs		
Blended Portland cement	1 t	ECONOTEC and IW

Blast furnace cement production

Material Inputs		
Portland cement clinker	0,30 t	MATTER
Blast furnace slag	0,65 t	MATTER
Gypsum	0,05 t	FEBELCEM
Energy Inputs		
Electricity	0,26 GJ	ECONOTEC and IW
Low temperature steam	0,40 GJ	MATTER
Material Outputs		
Blast furnace cement	1 t	ECONOTEC and IW

Table 14.- Material and energy input/output in clinker and cement manufacturing by process and type of cement

Prefabricated concrete production

Material Inputs		*Source*
Cement	0,2 t	MATTER
Gravel and sand	0,7 t	MATTER
Energy Inputs		
Electricity	0,01 GJ	MATTER
Gas oil	0,03 GJ	MATTER
Material Outputs		
Prefabricated concrete	1 t	MATTER

Ready mix concrete production

Material Inputs		
Cement	0,13 t	MATTER
Gravel and sand	0,8 t	MATTER
Energy Inputs		
Electricity	0,01 GJ	MATTER
Natural gas	0,03 GJ	MATTER
Gas oil	0,03 GJ	MATTER
Material Outputs		
Ready mix concrete	1 t	MATTER

Concrete building block production

Material Inputs		
Cement	0,15 t	MATTER
Energy Inputs		
Electricity	0,1 GJ	MATTER
Material Outputs		
Concrete building block	1 t	MATTER

Table 15.- Material and energy input/output in concrete manufacturing by type of concrete

4. THE GLASS INDUSTRY

4.1. Glass production and consumption in Belgium[18]

Belgian glassmaking annual output is 1,5 million tonnes of molten glass.

Belgium is the second biggest flat glass producer in Europe. Flat glass accounts for over 60% of the total glass produced in Belgium, contrary to the other European countries where hollow glass accounts for over 60%.

Belgium-Luxembourg production (around 150 kg per capita) is almost three times greater than apparent consumption (50 kg per capita), whereas in other European countries the volume of glass production is roughly equivalent to apparent consumption.

Belgian glass companies manufacture 5% of the tonnage produced in Europe and they account for 11% of the combined extra-Community glass exports of all the EU member countries. Belgium is thus the second largest EU glass exporter, just behind Germany.

Belgian glass companies employ around 5% of all the workers in the EU glass industry. In 1996, the Belgian glass industry directly employed 12000 people.

4.2. Product characterisation

The primary glass industry has evolved into four distinct segments:

- Flat glass (used largely for windows, auto windshields, mirrors and tabletops);
- Hollow glass (such as bottles and jars, bulbs and tubes, etc);
- Fiberglass (for insulation and structural applications) and
- Specialty glass (such as microspheres, cellular glass, glass for electronics and solar technology, ornamental glass, fiber optics and scientific and medical equipment).

The flat glass industry produces four main products: tempered glass, laminated glass, glass mirrors, and insulating units.

- Tempered glass is a type of safety glass stronger than ordinary glass. Its particularity being that when shattered it breaks into a multitude of tiny pieces without jagged edges.
- Laminated glass consists of two or more layers of glass separated by, and bonded to, thin sheets of plastic that prevent the glass from shattering when broken. The automobile industry is the largest market for laminated glass.
- Glass mirrors are produced by cleaning the glass and coating it on one side with an adhesive, reflective, and binding compound.
- Insulating units consist of two or more parallel separated panes of glass joined at the edges by metal seals or by fusing the edges, with the space between the panes either evacuated or filled with dry air or another gas. Insulating units are used to reduce surface condensation, to reduce sound transmission, and for thermal insulation.

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[18] Sources: OBCE and Glass Industry Federation.

The hollow glass sector covers the manufacture of glass containers (bottles and jars), glass tableware and crystal glass.

- The glass container industry produces three major products: food, beer, and beverage containers. Other markets for glass containers include: liquor; wine; medicine and health; toiletries and cosmetics; and chemical, household, and industrial products.
- The glass tableware industry produces the extensive range of drinking glasses.
- The crystal glass industry can be divided into three main group of products: domestic glassware for everyday use; decorative ware such as vases and dishes; giftware such as clocks, ashtrays and boxes.

The fiberglass industry produces two main products: textile fiberglass (electrical glass), and insulation fiberglass.

- Textile fiberglass is used in the production of fireproof cloth, and
- Insulation fiberglass is used in thermal and acoustical insulation.

A distinction is made between two types of glass facilities: the first covers glass and glassware establishments which produce bowls, goblets, lenses, jars, tableware, and other products which are pressed, blown, or shaped from glass produced in the same establishment, while the second covers facilities which manufacture products made of purchased glass, such as furniture, mirrors, windows, table tops, and laboratory glassware.

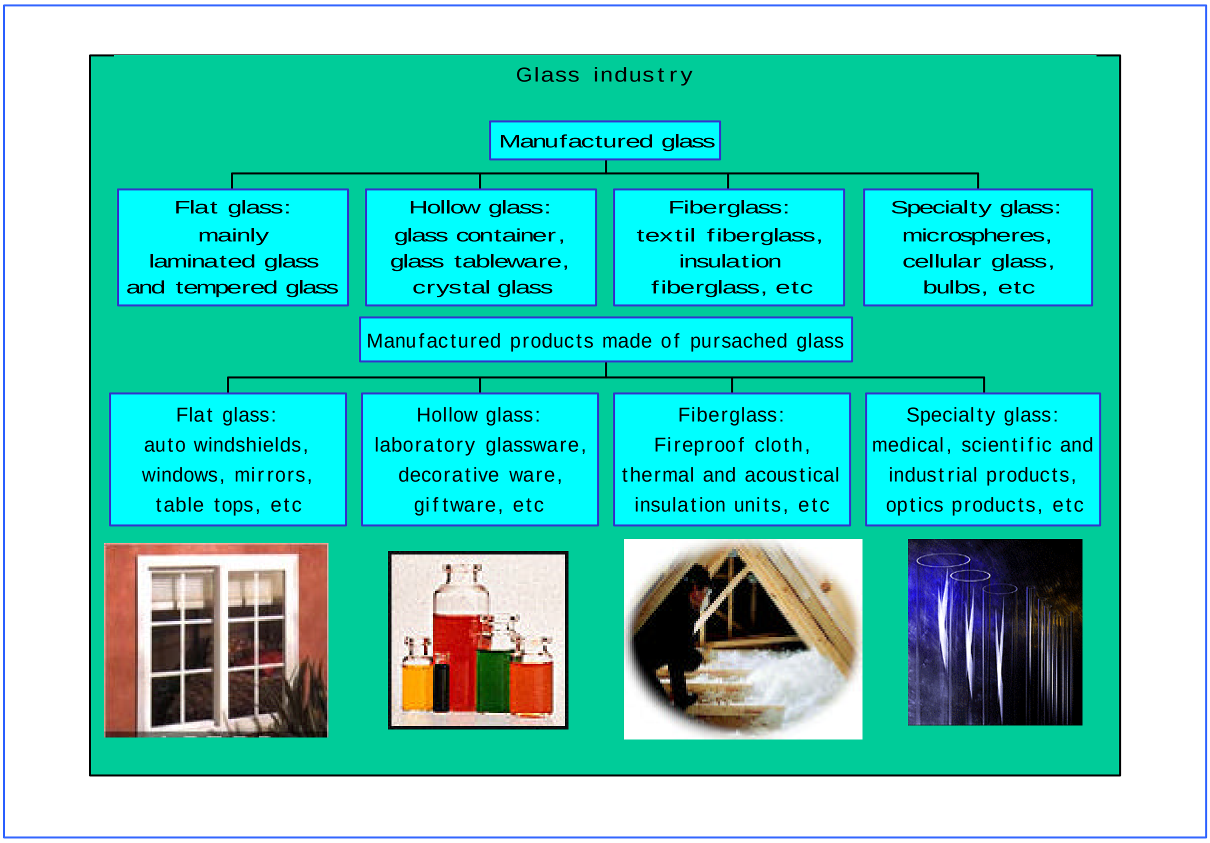

Figure 6.- Products characterisation in the glass industry

4.3. Main production routes in the glass industry

Production of glass involves five main procedures: mixing, melting, forming, annealing, and finishing.

- The two principle kinds of *mixing* are wet mixing and batch agglomeration. Glass with a large silicon dioxide content is wet mixed. Glasses with high lead oxide are mixed by batch agglomeration. The mixed batch is delivered to a melting unit through a feeder.
- The type of *melting* unit employed depends on the quantity and quality of glass to be processed. For small production and special glass, melting is performed in pot furnaces or crucibles containing up to two tonnes of glass. In large factories, a dozen or so pot furnaces may be heated by one central furnace. Larger batches are melted in large covered furnaces or tanks to which heat is supplied by a flame. For high quality glass, small continuous melting tanks are used to process low volumes of material. Large quantities of high quality glass are melted in continuous regenerative furnaces that recover waste heat from burned gases. Flat glass furnaces provide a larger amount of quality glass and are longer than furnaces used by glass container manufacturers. Although glass tanks are fired by gas or oil, auxiliary heating with electricity is commonly used.
- After the glass has melted, the molten glass is taken from the tanks to the *forming* operation, which is different for each type of glass product.
- Once formed, all glass articles need to be slowly cooled or *annealed*, usually in a long oven called a lehr. The purpose of annealing is to reduce the internal stresses which can crack the glass during cooling. Internal stresses are created because of temperature variations throughout the piece; different parts of the glass become rigid at different times.
- The two types of *finishing* processes are mechanical and chemical. Mechanical processes include cutting, drilling, grinding, and polishing. Chemical treatments are used to alter the strength, appearance, and durability of the product. Once finished, the glass products are cleaned using several agents, including aqueous solvents (chromic and sulfuric acid mixtures, detergent solutions), organic solvents (used alone or mixed with commercial cleansers), and hydrocarbon or halocarbon solvents (removal of nonpolar organic compounds).

Flat glass is typically made by the float process. The raw materials used in this process include silica sand, soda ash, limestone, dolomite, cullet (pieces of broken glass), and small amounts of other materials. These materials are proportioned to meet certain physical characteristics, mixed, and fed into the melting tank, where temperatures of about 1,600°C reduce the material to glass. Colouring agents may be added at this time to produce differing degrees of translucence. The molten glass is then fed as a continuous ribbon from the furnace into a bath of molten tin where it floats (glass is lighter than tin) and is fire polished. The ribbon of glass leaves the float bath and enters the annealing lehr where it is gradually cooled to prevent flaw-causing stresses. The glass is then cut. At this point, the glass may be packaged and sent to a customer, immediately subjected to further processing, or sent to storage for inventory or future processing. Additional processing often involves coating glass with thin layers of metal or chemical compounds that absorb infrared light or improve the reflecting qualities of the glass.

Hollow glass is mainly produced in gas and oil fired furnaces. There are a few electric furnaces. The most important raw materials are silicasand and cullet. The molten glass must be completely homogenised before it can be formed into the products. Small bubbles are removed using mainly sodium sulphate, which decomposes to gaseous oxides. Container glass products such as glass bottles and jars are sometimes mouth blown, but are typically formed with automatic machines. In automatic processes, a stream of glass is cut by shears into individual gobs, which are fed to a blank mold. The gob is then formed into a rough blank, or parison, by either a plunger or compressed air; at this stage the bottle opening is shaped. The blank mold opens and is then transferred to the final or blow mold, where it is blown into shape using an air compressor. Pressing is used to form flat items such as lenses and plates by pressing the glass between a plunger and a mold. Drawing and casting are forming processes which involve pouring molten glass into a mold.

Glass fiber manufacturing involves the high-temperature conversion of raw materials into a homogeneous melt, followed by the fabrication of this melt into glass fibers. The two basic types of glass fiber products, textile and wool, are created by similar processes. Glass fiber production can be separated into three phases: raw materials handling, glass melting and refining, and glass fiber forming and finishing. The primary component of glass fiber is sand, but it also includes varying quantities of feldspar, sodium sulphate, boric acid, and other materials. These materials are conveyed to and from storage piles by belts, screws, and bucket elevators. In the glass melting furnace, the raw materials are heated and transformed through a series of chemical reactions into molten glass. Glass fibers are made from the molten glass by one of two methods. In the rotary spin process, which dominates the fiberglass industry, centrifugal force causes molten glass to flow through small holes in the wall of a rapidly rotating cylinder to create fibers that are broken into pieces by an air stream. The flame attenuation process utilises gravity to force molten glass through small orifices to create threads which are attenuated, or stretched to the point of breaking by hot air and/or flame. After the glass fibers are created (by either process), they are sprayed with a chemical resin to hold them together, collected on a conveyor belt in the form of a mat, cured, and packaged.

4.4. Technological Perspectives

At the outset, following the petrol crises of the seventies, the development of glass recycling answered a vital need for energy savings.

4.4.1. Glass Recycling

The use of cullet in a glass furnace significantly reduces the energy consumption. This is due to the fact that cullet needs only to be melted and fined to produce glass. Thus, energy for chemical fusion reaction is not necessary. For every 10% cullet in the batch, 2,5 to 3% of energy is saved.

The amount of waste recycled in the various glass sectors depends strongly on the amount of cullet that is available for that sector and the glass quality requirements.

Distinction should be made between internal cullet (recycled glass from the own production line) and external cullet (recycled glass for consumer).

The use of internal cullet can be applied in all sectors without difficulties, although restrictions occur in the glass wool and fibre glass sectors as they can not recycle their internal waste directly. This is due to the organic binders and conditioners applied and to the product characteristics.

The composition of external cullet is less well defined and this limits the application of external cullet mainly to the container glass and mineral wool industry. Flat glass requires higher quality demands that might limit the amount of external cullet used and the availability of external cullet is lower.

In the container glass industry cullet levels of more than 90% of the total batch can be found. This implies an very significant energy saving potential of up to 30% compared to a furnace using only a normal batch.

Every tonne of cullet used makes a total savings of 100 kg of fuel: 40 kg for the melting of glass and 60 kg through limiting extraction, processing and the transport of raw materials[19].

Belgium has a collection system for consumer glass. The collected glass is cleaned, sorted by colour and sold to the glass industry, mainly to the container glass and glass wool industries.

4.4.2. Melting furnaces

The basic processing for glass production involves heating of silica and additives at high temperature. The major energy-intensive processes of the industry involves glass tank furnaces and annealing of glass in ovens after forming.

There are two types of glass melting furnaces.

- Pot Furnaces are structures built of refractory materials in which there is no contact between the furnace and the glass. Glass is melted in several pots made of refractory materials which are resistant to glass attack at high temperatures. The pots are charged with a batch, which is melted over a number of hours and worked on a 24 or 18 hour cycle. An average pot can hold 600-700 Kg of glass. Pot furnaces are used where the glass is formed by hand and mouth blowing. One of the main advantages of this system is that several types of glasses can be melted at the same time. A pot can be used for about 30 melting cycles and thus produce between 18 and 21 tonnes of glass.

  Pot furnaces are used for the small quantity production of multiple product types.

  Fuel economy is normally achieved by recuperation, i.e., the pre-heating of combustion air by waste heat from the furnace exhaust gases. In this system the pre-heating of the combustion air is done by passing the air through metal tubes on the outside of which the exhaust gases flow towards the chimney. Thus the heat exchange is continuous. Electricity can also be used for melting.

- Tank Furnaces are used where continuous flow of glass is needed to feed automatic glass forming machines. They are more economical in their use of fuel and are used mainly for the large scale production of containers, flat glass, electric bulbs, tubing and domestic machine made tableware. Tank furnace is a large furnace that permits to produce high-quality glass. This type of furnace is often used for production of flat glass or container glass. A large float glass furnace can have a capacity of 2,000 tonnes. A tank furnace consists of a bath, built of a very special high refractory material, which can resist chemical attack of molten glass at temperatures in excess of 1500°C and a superstructure where combustion takes place. The quality of refractory materials, used for building the bath, has improved to such an extent that whereas some 30 years ago, the life of a furnace was well below 2 years, it is now over 9 years.

  In the continuous operating tank furnaces, distinction is made between all electric and oil/gas-fired furnaces. All-electric furnaces are very efficient in their use of the energy fed to the furnace because there are no flue gases from the process (apart from some CO2 from dissociating minerals), but they are expensive because of the reduced furnace campaign life (of approximate 2 years) compared with oil/gas fired furnaces and the melting energy cost.

In today’s glass industry, the application of all electric melting is almost entirely limited to small special glass and glass wool furnaces because of the improved quality of the glass (as the elimination of volatile losses from the melt result in a more homogeneous glass). In principle, all electric melting

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[19] Source: Organisation Verre-avenir (France).

would be possible in all glass melting furnaces, but the main reason for not doing so is the cost of electric power.

An operating practice in oil and gas-fired furnaces has shown that effective use of electricity near the back end of the furnace, where the batch is added, can reduce fossil fuels needs or can be used to boast the glass production (electric boosting). Electric boosting is commonly applied in direct fired furnaces and might serve different purposes. With dark coloured glass, electric boosting is used to heat the deepest part of the melt. In other cases, the capacity of the furnace is increased by electric boosting. In general, electric boosting may provide between 3 and 20% of the total energy requirements to the melting process (not corrected for primary energy requirements of electric generation).

In order to achieve high melting temperatures and fuel economy, a regenerative or recuperative system is used. Both these systems utilise the waste heat of combustion for pre-heating the incoming combustion air. While in the recuperative system the heat exchange between the combustion air and waste gases is continuous, in the regenerative system the waste gases are passed through a large chamber packed with refractory bricks arranged in a pattern which permits free flow of the gases. The brickwork is heated by the waste gases and after having been heated for some 20 minutes, the direction of firing is reversed. Combustion air is passed through the chamber and the heat thus collected in the brickwork is used for pre-heating the combustion air. The firing is thus from right to left, normally for 20 minutes, during which time the right hand generator is heated and so there is a reversal of firing every 20 minutes. The cycle time can be changed for best heat exchange results and modern furnaces have computer managed control systems, which adjust the time of firing in each direction to achieve the best heat exchange conditions. The most and largest furnaces are continuous regenerative furnaces which are typically employed for glass container manufacturing. Recuperative furnaces are often used in the production of textile fibre glass because they maintain a constant temperature.

Flat glass and container furnaces are usually large cross-fired regenerative furnaces. Glass wool furnaces are usually medium sized cross-fired recuperative furnaces.

Heavy fuel oil or natural gas is normally used for firing tank furnaces. Glass, being an electrical conductor at high temperature, can also be melted by electricity. However, electricity is far too expensive and is normally used to boost the output from a gas or oil fired furnace.

Nevertheless, technological progress in electric melting has enabled the use of all electric glass melting furnaces even at the high cost of electricity.

4.5. Current and future technology and capacity

Table 16 presents the expected evolution of production capacity in the Belgian glass industry estimated from the investments plans of major facilities (synthesised bellow).

	1995	**2000**	**2005**	**2010**
Capacity (million tonnes)	2	2	3	3

Table 16.- Glass production capacity

In Belgium flat glass is produced in a small number of facilities with a large daily capacity of 250 to more than 500 tonnes. The melting furnaces are mainly oil (heavy oil) and gas (natural gas) fired. Container glass is produced in furnaces that use fossil fuels for melting or furnaces that use electricity with a capacity of 250 tonnes per year. All furnaces use heat recovery systems (large facilities are equipped with regenerator chambers and small facilities with heat exchangers). Fiberglass is produced in recuperative furnaces.[20]

Lifetime of a fuel consuming furnace is about 10 years and of a electricity consuming furnace is about 4-5 years.

4.5.1. Raw materials

Two Belgian companies dominate the world market in two raw materials:

- SOLVAY is the world's leading producer of sodium carbonate (also known as soda ash). It is also the world number one in barium and strontium carbonates used in high-quality glasses.

- SCR-Sibelco has played a pioneering role in quartz sand extraction and refining for over 125 years. The company's development (120 plants in 4 continents) has always remained associated with the Belgian extraction sites located in the Kempen area of Antwerp and Limburg and in Maasland.

Two energy intensive processes are used to produce soda, a raw material for glass production:

- The Solvay method

$CaCO3 + 2 NaCl = Na2CO3 + CaCl2$

$CaCl2 + CO2 + H2O + 2 NH3 = 2 NH4Cl + CaCO3$ (prec.)

The process combines calcium carbonate and rock salt to produce soda ($Na2CO3$)

- Caustic soda production

$CaCO3$ + heat = CaO (lime) + $CO2$

$CaO + H2O = Ca(OH)2$

$Ca(OH)2 + Na2CO3 = 2 NaOH$ (caustic soda) + $CaCO3$ (prec.)

The process has nowadays been abandoned in favour of electrolysis of NaCl

4.5.2. Flat glass

4.5.2.1. Glaverbel

Glaverbel is the leading flat glass producer in Benelux and in Central Europe and it is in the third position in Europe.
Glaverbel's annual float glass production capacity is 1450000 tonnes, corresponding to 15% market share in Europe. Glaverbel plans to increase flat glass production capacity at Moustier through the

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[20] ECONOTEC

installation of a new float. Some 87 million euros (3.5 milliards BF) will be invested in the fourth float at Moustier. It will be operational in the 4th quarter 2001 and will bring flat glass capacity from 1800 t/day to 2500 t/day.

The world biggest mirrors factory is Glaverbel Zeebrugge.

Splintex Mirodan (Heule), a specialist in the cutting and processing of glass, produces decorative mirrors and glass furniture.

4.5.2.2. Glaceries de Saint-Roch

Saint-Gobain Benelux is a world leader in technological materials.

The group's biggest company in Benelux is Saint-Roch, which is a specialist in glazing.

Saint-Roch has two float glass units in Belgium. Saint-Roch also recently decided to equip its Auvelais plant with a coater (magnetron). Apart from installation of the furnaces, this investment of over 18,6 million euro (750 million BF) is the biggest made in this site by Saint-Gobain for a long time. The coater is high-tech equipment used to apply thermal and solar control coatings on glass. The Saint-Gobain group was looking for an appropriate site in Northern Europe, close to a float glass unit, to install a new coater. The presence of two float glass units at Auvelais was a decisive factor in the decision to make this major investment. The new coater will be the acme of high performance in the Saint-Gobain group’s Glazing business. Coating glass with one or more thin metal layers gives its a whole range of new properties, such as more efficient heat insulation and solar control, which allows light through selectively but not heat. Coated glass production potential is substantial. The Netherlands and Germany are two countries with very strict heat insulation coefficient requirements for new buildings. These markets have therefore literally exploded: nearly half the float glass unit’s production is used to make double glazing and over half of the latter consists of at least one coated glass pane. It is expected that this trend will quickly become the norm in the rest of the European market and even the world market. The Auvelais coater line will become operational during summer 1998 and industrial-scale production will start in early 1999. Its annual capacity is likely to top 3 million m² of glass and Saint-Roch expects to sell most of the thermally insulated glass produced in the Benelux market, while the solar control products range will be sold in the world market.

Isover, another division of the Saint-Gobain group, is the world's leading producer of mineral wool for thermal, acoustic and fireproofing applications. In Belgium, Isover is one of the leading specialists in sloping roof insulation.

4.5.2.3. Other flat glass producers

- Spiegelfabriek Deknudt produces unframed mirrors for the furniture and bathroom sectors.
- Deknudt Decora manufactures a wide range of decorative mirrors for the interior decoration sector.
- Energiek Verwarmingstechnieken manufactures mirror radiators.
- Meyvaert Glass Engineering (Ghent) is specialist in safety glass.
- Groven is one of the leading façade builders in Benelux.
- Rioglass Belgium opened its Fleurus production unit in February 1998. It represents an investment of 110 million BF. Production capacity will be 25 panoramic windscreens (windshields) per eight-hour period, a two-shift system will operate resulting in a daily production rate of 50 windscreens.
- Roelants Glas manufactures interior glass for shop windows, offices and private housing.
- Solaglas Polypane is a leading processor of multifunctional glass products for the residential and project markets.
- Soliver produces mainly insulating glazing, glazed doors and door furniture at Waregem and laminated and tempered safety glass and car glass at Rumbeke.

- Sprimoglass produces double glazing, laminated glass, reflective glass and acoustic glazing.

4.5.3. Hollow glass

4.5.3.1. Manufacture du verre and Verlipack

Verlipack is a leading glass container producer. The company has invested in the production of very light glass containers.

4.5.3.2. Durobor

Durobor is one of the Europe's leading glass tableware manufacturers.

4.5.3.3. Nouvelles Verreries de Momignies

Nouvelles Verreries de Momignies is specialist in small bottles used in the perfume and cosmetic sectors.

4.5.3.4. Other hollow glass producers

- AHA Creativity manufactures a wide range of blown glassware, mainly vases, dishes and lighting for interior decoration.
- Cristallerie du Val Saint-Lambert manufactures mouth-blown and hand-shaped crystal glass as well as pressed glassware.
- EMGO is the world's leading producer of lamp glass (bulbs and tubes). It is a supplier of semi-finished glass products for the lighting industry.
- Euroterm produces glass inners, food containers and ice buckets.
- Hainaut Cristal Manage produces mouth-blown and hand-shaped wares.
- Sylvania Lighting International produces standard incandescent lamps, discharge lamps and halogen lamps at Tienen. This plant is a pioneer in low-voltage (230 V) halogen lamps.
- Vetro artistico creates an extensive range of decorative wares.

4.5.4. Fiber glass

4.5.4.1. Owens Corning

Owens Corning has two plants in Belgium. The plant at Battice produces glass fiber used mainly in the automotive, construction, aeronautics, IT and electronics sectors. The plant at Vise produces glass wool for building insulation.

4.5.5. Specialty glass

- Amos (Advanced Mechanical and Optical Systems) manufactures optical glass.
- Buchmann Optical Holding manufactures and distributes spectacle lenses.
- Duveco is specialist in the decoration of glass containers and ornamental glass using the coated process.
- Homarium produces double-glazed aquariums in acrilic glass.
- Pittsburgh Corning Europe produces Foamglass (cellular glass) at Tessenderlo.
- Sadems produces articles for laboratories.

- Solel produces solar collectors.
- Sovitec Cataphote is the world's second-biggest producer of glass microspheres.

4.6. Environmental Perspectives

4.6.1. GHG emissions

Glass materials used in the furnace are carbonates such as soda ash (Na_2CO_3) and limestone ($CaCO_3$). They are decomposed during the reaction for vitrification to discharge CO_2. These process emissions accounts for 13% of the global CO_2 emissions while electricity consumption accounts for 20% of the global CO_2 emissions.

Energy consumption differs according to the product types and the scale of production. The melting process is the greatest energy consumer in both the plants provided with tank furnaces for continuous production and the plants provided with the pot furnace for small quantity production of multiple product types. More than half of the energy consumption in the glass production process is accounted for by the melting process (75% for the tank furnace and 85% for the pot furnace).[21]

By all electric melting, emissions to air from the melter are minimised or totally avoided. However, considering emissions from the generation of electricity, conventional power plants operate with only 40% electric efficiency. So, real improvement can only be achieved when the electricity is generated by renewable sources.

The electric energy consumption to melt 1 kg of soda-lime glass from raw materials with an electric furnace is about 0,7 – 0,9 kWh. This corresponds to 2,5 – 3,3 MJ per kg glass. However, to produce this amount of electric energy, the equivalence of 7 to 10 MJ of primary energy carriers are used in an electric power plant. Thus, electric melting will only lead to energy savings in relatively small recuperative furnaces.

Table 17 shows the energy consumption and CO_2 emissions per type of glass-product.

Type of glass	Combustion GJ/t	Electricity KWh/t	Process t CO2/t molten glass	CO2 emissions t/t molten glass
Flat Glass	8,0	218	0,17	0,8
Hollow Glass	12,9	782	0,17	1,2
Other Glass (Fiber Glass included)	9,9	646	0,17	0,9

Table 17.- CO2 emissions by type of glass
Source: Econotec and IW

In 1996, 50% of CO_2 emitted by the glass production industry in Belgium came from flat glass production, 30% from container glass production, 14% from fiber glass production and 6% from glass transformation.

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[21] UNIDO

4.6.2. GHG emissions mitigation

Walloon glassmakers (Glaverbel, Saint-Roch, Owens Corning, Durobor, Verlipack and Nouvelles Vereries de Momignies) have signed a sector agreement in May 1995 with the Walloon Region to limit emissions of pollutants (particulate matter, NOx, SOx, HF, HCl and heavy metals) from their facilities. The targets set by the agreement have to be met by the year 2005.

IPCC list of improvement options applied to the glass industry

4.6.2.1. Fuel switch

Natural gas has a higher ratio of hydrogen to carbon than the other fuels and its use reduces overall emissions of CO2 by up to 25% for a given pull rate.

4.6.2.2. Increased energy efficiency and cleaner technologies

It is possible to make energy savings by the progressive replacement of the less effective furnaces and by an optimised recuperation of residual heat from smoke, already existent in some furnaces.

4.6.2.3. Recycling

Cullet has become the principal raw material in some glass manufacturing industries. It is melted in the factory furnaces to produce new glass that presents exactly the same qualities (aspect, impermiability, …), as if it had been produced from natural raw materials. Glass can be recycled indefinitely without any loss of quality.

Increased glass recycling is a way to reduce energy consumption because the energy for chemical reactions can be saved and raw materials decomposition is avoided. In addition, the production of soda is reduced. In Belgian glass industry, an increase of 10% of cullet quantity used reduces the furnace consumption in 1-1,5%. This possibility, however, is limited depending on the type of glass product. Flat glass and fiberglass manufacturing needs cullet of quality what limits recyclage rate to 15% while container glass manufacturers use 50% of cullet[22].

The information provided by the Belgian Government to the European Commission in the framework of the Belgian "translation" of the EU directive 94/62/EC indicate that a recycling rate of 55% of glass packaging had already been achieved in 1997 and that no capacity problems exist for absorbing the brown and green glass packaging waste arising. Recycling capacities are ensured by the existence in Belgium of a site capable of recycling 160000 tonnes of glass per year as well as of five treatment sites which produce secondary material which is demanded both by Belgian and foreign recyclers. White glass is exported to foreign industries which are willing to buy such wastes. (see 99/652/EC: Commission Decision of 15 September 1999 confirming the measures notified by Belgium pursuant to Article 6(6) of Directive 94/62/EC of the European Parliament and the Council on packaging and packaging waste (notified under document number C(1999) 2919) - Official Journal L 257, 02/10/1999 p. 0020-0023).

Any increase in the amount of glass recycled means savings on waste collection and waste disposal costs.

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[22] Econotec

4.6.3. Other environmental impacts

Emissions from the production of glass are generated during the handling of raw materials, the melting and the downstream processing. The transport and mixture of the crushed and powdered raw materials causes significant dust emissions.

Emissions generated by the melting of raw materials are mainly:

- Particulates, nitrogen oxides, and sulphur oxides generated from the combustion of fuel and
- Chlorides, fluorides and NOx generated from the volatilisation and the decomposition of batch materials.

Emissions of hydrocarbons can also be generated during the forming and finishing of glass products as a result of thermal decomposition of lubricants.

Furnace slag consists of chunks of unused molten glass which collect in the incinerator portion of the furnace. The composition of the slag is primarily magnesium oxide and sodium sulphate.

Much of the glass in the waste stream is not generated during the manufacturing process, but results from disposal of used glass products.

Flat glass production

Material Inputs		*Source*
Soda	0,26 t	MATTER
Gravel and sand	0,95 t	MATTER
Energy Inputs		
Electricity	0,80 GJ	ECONOTEC and IW
Heavy gas oil	5,84 GJ	ECONOTEC and IW
Natural gas	2,08 GJ	ECONOTEC and IW
Gas oil	0,16 GJ	ECONOTEC and IW
Material Outputs		
Flat glass	1 t	ECONOTEC and IW
Emissions		
Direct carbon dioxide	0,17 t	ECONOTEC and IW

Fiber glass production

Material Inputs		
Soda	0,01 t	Calcul à verifier
Gravel and sand	1,13 t	Calcul à verifier
Energy Inputs		
Electricity	2,33 GJ	ECONOTEC and IW
Natural gas	9,9 GJ	ECONOTEC and IW
Material Outputs		
Fiber glass	1 t	ECONOTEC and IW
Emissions		
Direct carbon dioxide	0,17 t	ECONOTEC and IW

Table 18.- Material and energy input/output in glass manufacturing by glass type

Solvay soda ash production

Material Inputs		*Source*
Quicklime	0,6 t	MATTER
Energy Inputs		
LT steam	10 GJ	MATTER
Material Outputs		
Soda	1 t	MATTER

Soda production (heavy)

Material Inputs		
NaOH	0,75 t	IW
Energy Inputs		
LT steam	4 GJ	ECONOTEC and IW
Material Outputs		
Soda	1 t	ECONOTEC and IW

Table 19.- Material and energy input/output in soda production by technology

5. THE LIME INDUSTRY

5.1. Lime production and consumption in Belgium

With an annual production of around 2000 ktonnes of lime, the Belgian lime industry is characterised by 6 lime-producing installations.

The production of lime in Belgium dropped in the 1980s as a consequence of changes in patterns of consumption. One of the main users of lime, the iron and steel industry, reduced its specific lime consumption per tonne of steel from 100 kg to 40 kg. In recent years, growth in the lime production has been attributable to a need for environmental control due to the introduction of more stringent regulation. Therefore, the growing use of lime for environmental protection brought sales back up again in 1985. Major environmental uses of lime include the treatment of liquid wastes and industrial effluents. Air pollution control is also a major and growing market for lime.

Within some industries, lime production is integrated with more complex operations to satisfy internal requirements as well as minimise transportation costs. For example, some sugar producers operate their own kilns beside their refineries. Therefore, the merchant lime industry represents only a portion of total lime production in Belgium.

Lime is a low-cost but bulky material, so it tends to be transported only over relatively short distances. In general, merchant plants are situated to take advantage of suitable limestone deposits and a nearby customer base. As a result, exports of lime from the EU only amount to a few per cent of the production. However, the main exporting country in the EU is Belgium, which exports nearly 50% of its lime production.

5.2. Product characterisation

Lime is a product derived from high temperature calcination of limestone. Although limestone deposits are common throughout Wallonia, only a small portion of these deposits is pure enough for industrial and agricultural lime manufacturing. To be classified as limestone, the rock must contain at least 50 percent calcium carbonate. When the rock contains 30 to 45 percent magnesium carbonate, it is referred to as dolomite or dolomitic limestone. Lime can also be produced from aragonite, chalk, coral, marble, and sea shells.

Quicklime, or burnt lime, is calcium oxide (CaO) produced by decarbonisation of limestone (CaCO3). Slaked lime are produced by reacting, or “slaking”, quicklime with water and consist mainly of calcium hydroxide (Ca(OH)2). The term lime includes quicklime and slaked lime.

A distinction is therefore made between calcium limes, dolomitic limes and hydraulic limes. Calcium limes are more specialised products and are supplied in smaller quantities in lump, ground, hydrated and dead-burned forms. Hydraulic limes are partially hydrated and contain cimentitious compounds, and are used exclusively in building and construction.

Different types of lime are used for a wide variety of applications and in a wide range of products, each suited to particular market requirements. Major uses of lime are metallurgical (steel refining, copper, gold, aluminium, and silver), environmental (flue gas desulfurisation, water softening and pH control, sewage-sludge stabilisation, hazardous waste treatment, acid neutralisation), for construction purposes (binder in building and construction, soil stabilisation, bitumen additive, and masonry lime), and agricultural (soil conditioning and pH control).

In general, lime is a low cost source of alkali with the functionality to react with acidic compounds in this variety of applications.

In iron and steel making, lime is used as a fluxing agent which reacts with silicon (Si), sulphur (S), phosphorous (P) and other impurities to form a protective slag on the molten metal. Lime is added to the basic oxygen furnace as well as ladles of molten metal. It is also used both in traditional basic oxygen furnaces (BOF) and the newer electric arc furnaces, as well as in secondary refining. Lime for use in the steel industry, both high calcium and dolomitic, must meet exacting specifications as to its physical and chemical properties.

Lime is also essential to producing metals other than steel. Thus, lime is used to beneficiate copper ore, to make alumina and magnesia for use in aluminium and magnesium manufacture, to extract uranium, and to recover gold and silver.

The paper industry uses lime as a causticizing agent and for bleaching and, increasingly, for producing precipitated calcium carbonate for use in the paper manufacturing process. In kraft pulp production lime is reacted with sodium carbonate to make caustic (sodium hydroxide) used to cook the wood fibres. An important and growing use for lime is in the production of high quality precipitated calcium carbonate. High brightness precipitated calcium carbonate, made by reacting CO_2 and hydrated lime (Ca(OH)2), is used as a filler, and to a lesser degree as a paper coating in some paper products. It is also used in the production of paint, ink, plastic, and rubber.

Lime is also used for environmental applications, involving air, drinking water, wastewater, and solid wastes. Industrial, utility and mining operations rely on lime to comply with a host of environmental regulations. Lime is used to treat industrial and mining wastewater, in which it adjusts the pH of acidic waste, removes phosphorus and nitrogen, and promotes clarification. A growing use of lime is in the treatment of stack gases from industrial facilities, power plants, medical waste incinerators and hazardous waste incinerators. Lime absorbs and neutralises sulphur oxides from these gases, helping to prevent acid rain, and also reduces emissions of hazardous air pollutants, including mercury. In these applications (water, sewage, effluent, soils treatment and gas scrubbing), lime neutralises various acidic components and typically forms inert calcium salts (e.g., calcium sulphate, phosphates) in the process. In terms of tonnage, lime is the most important chemical used in the clarification and softening of potable water. Lime is therefore especially vital to municipalities in meeting their environmental and public health responsibilities at a reasonable cost. First, lime is widely used for potable water softening and to remove impurities (such as lead) from drinking water. Second, it is a highly cost-effective method to treat sewage sludge. Third, stack gases from municipal incinerators are treated with lime to remove sulphur dioxide, hydrogen chloride and other contaminants.

In construction, lime has always been used as a bonding agent. Lime's traditional use is in mortar and plaster, because of its superior plasticity, workability and other qualities. Although slower in curing than pure cement mortar, lime (or bastard) mortar retains its advantage of plasticity and thus rapid application. Furthermore, masonry work with lime mortar has equal resistance, but is more impermeable, more flexible and less susceptible to cracks. Lime's dominant construction use today is in soil stabilisation for roads, airfields, building foundations and earthen dams, where it upgrades low quality soils into usable base and subbase materials. It is also used as an additive in asphalt, in which it improves the cohesion of the asphalt, reduces "stripping "and retards the aging process. Dolomitic lime is also used in the production of masonry mortar and stucco.

Several categories of building materials are used with lime and calcium carbonate: silica-limestone bricks, which combine lime and silica sand; yellow or salmon-coloured decorative bricks, obtained by decolouring the iron oxide of the clay by means of micronised calcium carbonate; concrete, in all its forms, which micronised calcium carbonate makes smoother, more elegant, less porous.

In addition, lime is being used increasingly in modern building materials, such as cellular concrete and lime-sand bricks. Autoclaved cellular concrete, light and insulating, is obtained from a gasified mortar based on silica sand, high calcium lime and cement. These materials are highly valued because they have excellent thermal and acoustic insulating properties and are easy to work with.

In addition to the uses described above, lime is essential to many other industries. For example, the chemical industry uses lime to manufacture sodium alkalies, calcium carbide, calcium hypochlorite, citric acid, petrochemicals, phenolates, stearates, naphthenates, nitrates, caseinates, calcium phosphates, propylene glycol, glycerin, and many others.

Other key uses of lime include refractories, sugar refining, agricultural liming, glass making, and leather tanning.

5.3. Main production routes in the lime industry

The basic processes in the production of lime are:

- quarrying raw limestone;

  The raw material for lime production is limestone or, to a lesser extent, dolomite or dolomitic limestone. Dolomite and dolomitic limestone are mixtures of calcium carbonate and up to 44% magnesium carbonate. Lime production generally uses between 1,4 and 2,2 tonnes of limestone per tonne of saleable quicklime.

- preparing limestone for the kilns by crushing and sizing;

  Limestone is quarried, crushed and washed.

- calcining limestone;

  The lime making process consists of the burning of calcium and/or magnesium carbonates at a temperature between 900 and 1500°C, which is sufficiently high to liberate carbon dioxide and to obtain the derived oxide. In that way, lime is manufactured in various kinds of kilns by one of the following reactions:

  $CaCO_3$ + heat = CO_2 + CaO (high calcium lime)

  $CaCO_3$ + $MgCO_3$ + heat = $2CO_2$ + CaO + MgO (dolomitic lime)

  In some lime plants, a by-product of lime manufacturing is ground limestone for agricultural purposes (aglime).

- processing the lime further by hydrating;

  The calcium oxide product from the kiln is generally crushed, milled and/or screened before being conveyed to silo storage. From the silo, the burned lime is either delivered to the end user for use in the form of quicklime, or transferred to a hydrating plant where it is reacted with water to produce hydrated or slaked lime.

- miscellaneous transfer, storage, and handling operations.

5.4. Technological Perspectives

Since the oil crisis of 1972, there have been a number of pressures on lime producers to replace existing kilns.

Many lime producers operates two or more types of kiln, using different sizes of limestone feed and producing different qualities of lime.

In Belgian facilities, most of the kilns currently used are based on either the shaft (14 kilns) or the rotary design (8 kilns). Rotary kilns generally require more heat than shaft kilns.

The different types of lime kilns, the hearth of a lime plant, are described bellow.

5.4.1. Vertical or Shaft Kilns

The prevalent type of kiln in Belgium is the vertical or shaft kiln. This kiln can be described as an upright heavy steel cylinder lined with refractory material. The limestone is charged at the top and is calcined as it descends slowly to discharge at the bottom of the kiln. A primary advantage of vertical kilns over rotary kilns is their higher average fuel efficiency. The primary disadvantages of vertical kilns are their relatively low production rates and the fact that coal cannot be used without degrading the quality of the lime produced.

5.4.2. Rotary Kilns

The next most common type of kiln in Belgium is the rotary kiln. The kiln is a long, cylindrical, slightly inclined, refractory-lined furnace, through which the limestone and combustion gases pass counter-currently. Coal, oil, and natural gas may all be fired in rotary kilns. Product coolers and kiln feed preheaters are commonly used to recover heat from the hot lime product and exhaust gases.

5.4.3. Rotary hearth or calcimatic and fluidised bed kilns

Other, much less common, kiln types include rotary hearth and fluidised bed kilns. Both kiln types can achieve high production rates, with fluidised bed kilns sometimes operating on coal. The calcimatic kiln, or rotary hearth kiln, is a circular kiln with a slowly revolving doughnut-shaped hearth. In fluidised bed kilns, finely divided limestone is brought into contact with hot combustion air in a turbulent zone, usually above the perforated grate. Because of the amount of lime carryover into the exhaust gas, dust collection equipment must be installed on fluidised bed kilns for process economy.

5.4.4. Annular Shaft or Parallel Flow Regenerative Kilns

Another alternative process that has recently emerged is the parallel flow regenerative lime kiln. This process combines two advantages. First, optimum heating conditions for lime calcining are achieved by concurrent flow of the charge material and combustion gases. Second, the multiple-chamber regenerative process uses the charge material as the heat transfer medium to preheat the combustion air. The basic parallel flow regenerative system has two shafts, but the shaft systems are used with small size grains to address the increased flow resistance associated with smaller feed sizes.

In the two-shaft system, the shafts alternate functions, with one shaft serving as the heating shaft and the other as the flue gas shaft. Limestone is charged alternatively into the two shafts and flows downward by the influence of gravity. Each shaft includes a heating zone, a combustion zone, and a cooling zone. The two shafts are connected in the middle to allow gas flow between them. In the heated shaft, combustion air flows downward through the heated charge material. After being preheated by the charge material, the combustion air combines with the fuel and then the fuel mixture is fired downward into the combustion zone. The hot combustion gases pass from the combustion zone into the heating shaft to the combustion zone in the flue gas shaft. The heated exhaust gases flow upward through the flue gas shaft combustion zone and into the preheating zone where they heat the charge material. The function of the two shafts reverses on a 12-minute cycle. The bottom of both shafts is a cooling zone. Cooling air flows upward through the shaft counter-currently to the flow of the calcined product. This air mixes with the combustion gases in the crossover area providing additional combustion air. The product flows by the force of gravity from the bottom of both shafts.

5.4.5. Hydrators

In some facilities, lime produced is converted to hydrated, or slaked, lime. To do so, there are two kinds of hydrators: atmospheric and pressure.

Atmospheric hydrators, the more common type, are used in continuous mode to produce high-calcium and dolomitic hydrates. Pressure hydrators, on the other hand, only produce exclusively a completely hydrated dolomitic lime and operate in batch mode. Generally, water sprays or wet scrubbers perform the hydrating process and prevent product loss. Following hydration, the product may be milled and then conveyed to air separators for further drying and removal of coarse fractions.

The energy requirement of different kiln lime types is presented in Table 20.

Kiln type	**Energy requirement (GJ/t lime)**
Long rotary kilns (typically with no preheat)	7 - 13
Rotary hearth or Calcimatic kilns	6 - 9
Short rotary kilns (typically with preheaters)	5.5 - 8.0
Shaft kilns (vertical)	5.0 - 7.0
Double shaft or annular shaft kilns	4.0 - 4.5

Table 20.- Energy Requirements for Different Kiln Designs in lime manufacturing
Source: Canadian Lime Institute

The age, type and specific design of the kiln operations are important elements determining differences in energy consumption between producers and between kilns. Typically, long rotary kilns without limestone feed preheating systems (which use recovered waste heat) consume the most energy per unit of lime produced. Shaft (or vertical) kilns, especially double shaft and annular designs, are typically more energy efficient than other designs. Short rotary kilns with feed preheating and product-contacting cooling systems are an efficient alternative design that has been increasing market penetration.

Some lime producers operate more than one type of kiln. This provides market flexibility and optimisation of total operational costs (including limestone quality, fuel, product specifications, throughput, etc.).

Energy can represent 40% of production costs and 25% of full costs (including interest and return to capital) of delivered product. Transportation is an important element in the cost structure and can be as high as 30% of full costs. By comparison, raw material preparation costs are usually a minor component for most lime plants that are situated next or very close to limestone quarries.

5.5. Current and future technology and capacity

There are 6 lime-producing plants in Belgium (excluding captive lime production) with a total of 29 kilns (14 regenerative shaft kilns, 8 rotary kilns, 5 annular shaft kilns and 2 other kilns).

Table 21 presents the evolution of production capacity in the Belgian lime industry estimated from the expected lime demand.

	1995	2000	2005	2010
Capacity (million tonnes)	3	3	3	3

Table 21.- Lime production capacity

It is very likely that demand for lime will continue to grow from environmental applications, including water treatment and flue gas desulphurisation. On the other hand, demands in the iron and steel industry, where lime functions mainly as a desulphurising agent, could decline gradually, as steel makers improve the efficiency of their operations and, as a consequence, reduce lime use.

Several facilities of two world leader companies in lime production (Lhoist and Carmeuse) are located in Belgium.

Lhoist is the world’s leading producer of lime and dolomite and the Carmeuse Group has become a world leader in the production and marketing of limestone and dolomitic products for industrial use (calcium carbonate, calcium/magnesium carbonate); lime (calcium oxide) and dolime (calcium/magnesium oxide); hydrated lime (calcium hydroxide).

Belgium’s Carmeuse is a specialist in extracting and processing calcium carbonate. Founded in 1860 in Liège, Carmeuse is today a leader in handling all forms of limestone and its derivatives, including quicklime (calcium oxide), slaked lime (calcium hydroxide) and dolomite (calcium and magnesium carbonate). The company has 94 production facilities in some 20 countries across Central and Western Europe, North America and Africa, employs 4,600 people and has an output capacity of 15 million tonnes of lime per year.

5.6. Environmental Perspectives

5.6.1. GHG emissions

Lime producers heat (or calcine) limestone to dissociate carbon dioxide. The lime burning process is the main source of emissions and is also the principal user of energy. The amount of energy required is related to such factors as: the type, age and specific design of the kiln (including the incorporation of energy recovery systems); the types of fuel; operating practices; and product grade and customer quality requirements.

Raw material and product preparations also consume fossil fuels and electricity for solids handling, crushing and transportation, but most of the energy in the total operation is consumed at the kiln.

Approximately 60% of CO_2 emissions are from the dissociation reaction inherent in making lime (process emissions). The remaining 40% of the emissions are energy related. Electricity consumption constitutes less than 5% of energy requirement.

Manufacturing	**Combustion GJ/t**	**Electricity KWh/t**	**Process t CO2/t quicklime**	**CO2 emissions t/t**
Lime	5,9	62,5	0,73	1,24 t CO2/t quicklime

Table 22.- CO2 emissions in Belgian lime manufacturing
Source: Econotec and IW

Total emissions are estimated at 1.24 tonnes CO_2 equivalent per tonne of lime made.

The dissociation of limestone produces up to 0,73 tonnes of carbon dioxide per tonne of quicklime, depending on the composition of the limestone and the degree of calcination.

The lime industry is a highly energy-intensive industry. The amount of CO2 produced by combustion depends on the fuel and the heat use per tonne of quicklime, generally it is in the range of 0,2 to 0,45 tonne CO2 per tonne of quicklime.

Nevertheless, a portion of the lime industry's CO_2 emissions may be offset by the sequestration of CO_2 in a number of end-use applications, including the manufacture of sugar, the use of lime in scrubbers, the concentration of certain metal ores, sewage and drinking water treatment, the manufacture of precipitated calcium carbonate and steel manufacturing.

5.6.2. GHG emissions mitigation

IPCC list of improvement options applied to the lime manufacturing industry:

5.6.2.1. Fuel switch

Lime producers select available fuels based on several criteria. These include price, efficiency and sulphur content. Sulphur content in lime is an important quality factor that relates to the ability of the supplier to meet customer specifications in the iron and steel market. There are trade-offs between fuels. For example, while natural gas is sulphur free, it is less efficient (energy required per unit of production) than other fuels, such as petroleum coke and coal. Natural gas can also dramatically decrease kiln capacity, although this can be a convenient option for some producers. Natural gas can be significantly more expensive than petroleum coke and coal, such that these heavier fuels may be preferred, especially when high sulphur content can be tolerated. Material flows inherent in long rotary kilns have the effect of scrubbing the sulphur (with lime) out of the final product. Therefore, these long rotary kilns can be used to make product for steel makers, which typically require low sulphur content lime.

Switch from coal to natural gas can contribute to reduce greenhouse gas emissions, but it should be noted that switching to natural gas, while resulting in reductions of direct greenhouse gas emissions can also result in a reduction in capacity and an increase in the generation of NOx.

5.6.2.2. Increased energy efficiency and cleaner technologies

By the nature of the limestone dissociation reaction, CO_2 generation is inevitable. However, CO_2 emissions per tonne of lime produced, can continue to decrease as long as lime manufacturers are able to increase their energy efficiency, for instance, by installing new, higher efficiency kilns and preheaters (subject to quality and design constraints) or high-pressure roll mills in order to minimise electrical energy use.

In fact, most technologies that can achieve a level of reduction at inefficient kilns are technologically proven and have already been adopted by some of the more efficient operators. However, the degree of market penetration among facilities in Belgium is not documented, and consequently, it is not clear which mix of reduction technology options best matches the overall needs of the industry for reducing greenhouse gas emissions. A more detailed examination of the state of operating practices (potentially versus a developed standard), fuel availability/delivery, and energy efficiency-enhancing equipment already employed within the industry would determine the optimal mix of greenhouse gas emission reduction technologies and their potential for adoption by facilities. This analysis would need to take into account product quality constraints and related market/customer orientation that are often different for each producer. Producers' ability to meet customer requirements in terms of sulphur content, reactivity (i.e., portion of CO_2 released), and particle size are among the important quality factors that can influence the type of kiln and fuels used. For example, shaft kilns are more energy efficient but can result in unacceptable sulphur (as calcium sulphate) carryover into the final product. Typically, this is not a problem with less efficient long rotary kilns.

In general, the least efficient operators may be able to apply low cost operational and equipment changes that may result in energy cost savings while the more efficient operators will be faced with much more costly options for reducing emissions.

5.6.2.3. Dematerialization and materials substitution

It is likely that lime users have already evaluated potential substitutes (e.g., soda ash, caustic soda, and limestone) in terms of costs and effectiveness. Although analyses of substitutes are outside the scope of this report, from the perspective of CO_2 emissions, a factor to be considered is that the use of lime may result in the direct reabsorption of CO_2. In fact, a portion of the CO_2 emitted in lime manufacture is reabsorbed from the atmosphere by chemical reactions induced by the use of lime.

On the other hand, lime is utilised by industries (and other end-users) that require calcium or hydroxide ions. The lime industry fulfils this demand by removing carbon dioxide from limestone to produce lime. Virtually all substitutes for lime are other alkali minerals, derived from a carbonate form. Making calcium and hydroxide ions from these source materials inevitably involves the release of carbon dioxide as well. Examples include soda ash production via calcination of ore and the use of limestone in steelmaking. In these cases, the CO_2 process emissions may occur at the point of manufacture (e.g., soda ash) or at the point of use (e.g., steel). However, shifting process emissions (e.g., from a lime plant to a steel mill substituting limestone) will not reduce emissions. More importantly, if substitutes are less effective than lime, more CO_2 may be emitted by the use of substitutes.

Substitutes will also require energy use that releases CO_2. For example, the energy requirements of caustic soda manufacturing are such that 20 percent more CO_2 is released per ton of NaOH (considering both energy and process emissions). The use of energy may occur at the point of manufacture or at the point of use. Shifting energy use emissions from a lime plant to a steel mill substituting limestone may not reduce emissions, depending on the relative efficiencies of the lime kiln and steel furnace. Again, if substitutes are less effective than lime, even more CO_2 may be emitted. Also, transportation-related energy use should be considered, as substitutes for lime will tend to involve transportation of larger quantities, either because substitutes will be transported in the heavier uncalcined form (e.g., limestone) or will be less reactive (e.g., soda ash).

As a result, instead of lime substitution, indirect opportunities to reduce greenhouse gas emissions relate to minimising lime usage in some application areas as well as using lime in applications where lime sequesters carbon dioxide. There are potential possible ways to minimise lime consumption in the various application areas: one example is in the iron and steel industry.

As CO_2 emitted by the lime industry may be recovered through end-use applications, full life-cycle analysis of lime based products would be useful in assessing the industry's net contribution to total greenhouse gas emissions and in order to better quantify net emissions associated with lime usage. Comprehensive analyses of this type, which would require an examination of the fate of lime and sequestering potential within such applications as iron and steel making, water treatment, and other applications, were not identified in conducting this study.

5.6.3. Other environmental impacts

The main releases from lime production are atmospheric releases from the kiln. These result from the particular chemical composition of the raw materials and fuels used. However, significant releases of particulates can occur from any part of the process, notably the hydrator. Potentially significant emissions from lime plants include dust, nitrogen oxides (NO_x), sulphur dioxide (SO_2) and carbon monoxide(CO).

Quicklime production

Energy Inputs		*Source*
Electricity	0,23 GJ	ECONOTEC et IW
Coal	0,09 GJ	ECONOTEC et IW
Petrol coke	2,9 GJ	ECONOTEC et IW
Heavy gas oil	0,06 GJ	ECONOTEC et IW
Natural gas	2,2 GJ	ECONOTEC et IW
Gas oil	0,3 GJ	ECONOTEC et IW
Coke	0,35 GJ	ECONOTEC et IW
Material Outputs		
Quicklime (CaO)	1 t	ECONOTEC et IW
Emissions		
Direct carbon dioxide	0,73 t	ECONOTEC et IW

Table 23.- Material and energy input/output in lime manufacturing

6. THE BRICKS INDUSTRY

6.1. Brick production and consumption in Belgium

Belgium is a large producer of bricks and tiles.

The evolution or brick production in Belgium in 1000 m3 is shown in Figure 7.

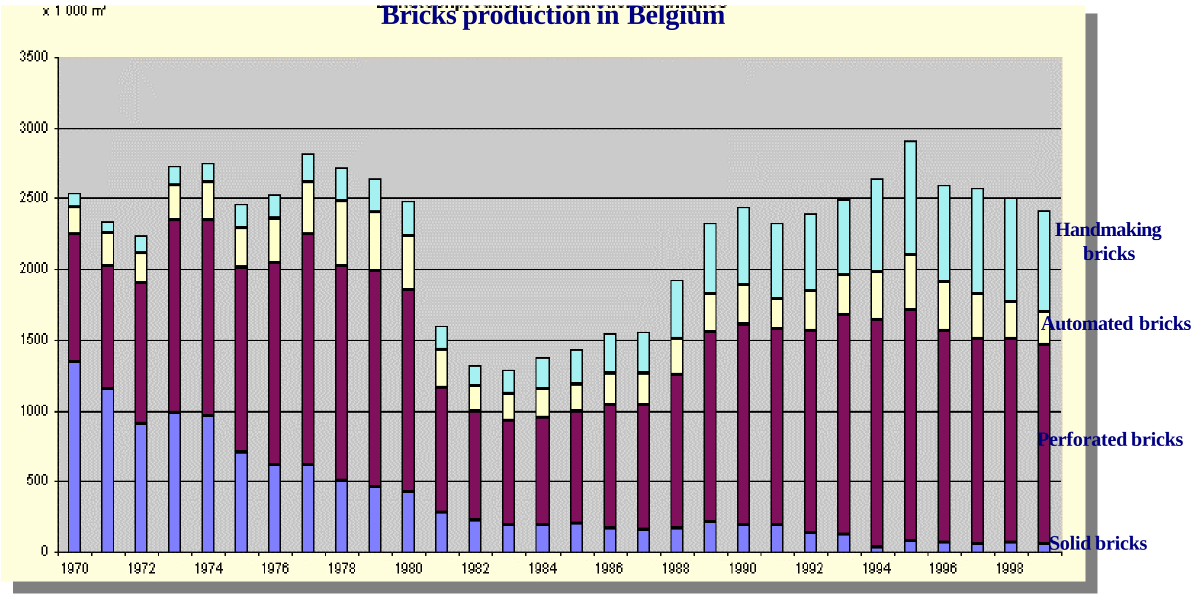

Figure 7.- Bricks production in Belgium
Source: Fédération Belge de la Brique

Structural clay products being high-volume low-cost articles, generally supply proximity markets; foreign trade in the brick and tile sector generally represents only a small proportion of total consumption. The Czech Republic is a major source of imports; Koramic-Terca is already participant in Czech Republic.[23]

6.2. Product characterisation

Faced with competition from a wide range of products based on concrete, wood, metal or plastics, the modern brick and tile sector is a primary supplier of the construction sector of Belgium.

Six main groups of structural clay products destined for the building sector can be identified:

- Stock, face and hollow bricks for inside and outside walls; these are the most widely used products and by themselves account for about 50% of total structural clay production.

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[23] European Minerals Yearbook, Second Edition 1996-1997. DG III of the European Commission.

- Gauged bricks, hollow bricks for floors and ceilings,
- Roof tiles, either flat, interlocking or channel shaped,
- Floor tiles
- Chimney blocks and ventilation-duct conduits,
- Drain pipes.

There are two categories of clay construction products: bricks and roof-tiles. The various brick styles are classified on the basis of national standards (BENOR). The Belgian norm NBN B – Bricks for masonry distinguishes the three categories of bricks show in Figure 8.

The first category comprises solid bricks in which the perforations represent less than 20 per cent of total brick volume. The most common format of this kind of bricks is 19 x 9 x 9 cm.

The second category includes perforated bricks in which the perforations are vertical and represent at least the 20 per cent of total brick volume. The perforations surface normally does not exceed 6 cm2.

The third category comprises hollow bricks in which the perforations are horizontal, they represent more than 20 per cent of total brick volume and their section exceed 6 cm2.

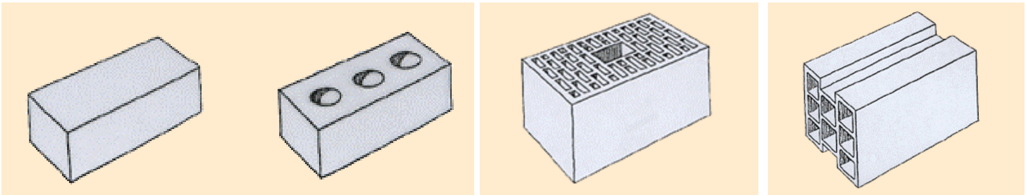

Figure 8.- Belgian Brick categories
Source: Fédération Belge de la Brique

6.3. Main production routes in the brick industry

Current manufacturing technology ranges from traditional hand methods to modern automated mass-production techniques. Regardless of the technology employed, however, the basics of brick/tile processing are the same: preparation of a raw mix, shaping, drying and firing.

The raw material used for manufacturing tiles and bricks is generally obtained by mixing several types of clay dug from clay pits along with sand (or even granulated slag, fly ash, etc, if available) to reduce drying shrinkage.

The aim of the first phase, the preparation of a raw mix, is to obtain a plastic and homogeneous body through initially grinding the raw clay, adding and mixing the various constituents in a mixer, screening for coarse material, grinding in a ball or hammer mill, and homogenising and wetting in a sieve mixer or in a wetter-mixer. Then the mix, sometimes with coal dust added to help the burning that comes later, is kneaded thoroughly by large revolving blades in a device called a pug mill. The mix passe through the pug mill to improve strength and cohesion and it is followed by either vacuum extrusion of the brick/tile to eliminate any trapped air or simple pressing in a die. Traditional brickmakers performed this work by hand.

The three principle processes for forming bricks/tiles are the stiff mud (involving substantial amounts of water mixed with the clay), soft mud (less water), and dry press (little or no water) methods. The stiff-mud process is the one most often used: all structural tile and most types of brick are formed by the stiff mud process.

In the stiff mud process, water is added to give the clay plasticity, and the bricks are formed by forcing the clay through a stiff-mud machine (like toothpaste from a tube) and cut by wires. The formed bricks are placed on devices called cars which carry them through tunnel dryers that remove about 400 grams of moisture from each brick in 24 hours.

The soft mud process utilises clay with a high moisture content. In the soft-mud process, clay is mixed with water and machines (or hand brickmakers) press the mixed clay in moulds to form the bricks. The brick that is produced this way is not as hard or durable as the stiff-mud brick.

In the dry press process, clay is mixed with a small amount of water. From nearly dry clay, bricks are formed in steel moulds by applying pressure. This type of brick is somewhat more expensive than those made by the other two processes. It is used for artistic front-wall finishes or decorative interior work.

When wet clay units come from moulding or cutting machines, they contain from 7 to 30 percent moisture, depending upon the forming method. Drying eliminates most of the water that gave the mixture sufficient plasticity for shaping. It is done in static or tunnel dryers. Most of facilities use dryer chambers. Drying temperatures rang from about 38°C to 204°C and drying time, which varies with different clays, is usually from 24 to 48 hours. Although heat may be generated specifically for dryer chambers, it is more commonly supplied as exhaust heat from firing kilns.

The next step is burning, in which the chemical properties of the clay are changed to give it strength and durability. Firing temperature varies from 860°C to 1100°C and it can take place in two types of kiln: continuous and intermittent kilns.

The two base designs of continuous kiln are annular and tunnel. In annular kilns the bricks/tiles remain stationary and the fire moves slowly around the kilns by the operation of a sequence of dampers. In the continuous tunnel kiln (the most modern automated type), bricks/tiles move slowly through the various temperature zones within the kiln and the fire remains stationary. Bricks are piled on a single fireproof car that passes with others through tunnels up to 150 meters long. They move from a preheating zone to the burning zone and then to a cooling zone.

In the intermittent kilns (semi-continuous), bricks remain stationary while the flame moves around them.

An earlier type of kiln, called the clamp, is sometimes used in Belgium: as many as 3 million bricks may be piled to form their own kiln. The bottom and top are vented and the sides are sealed with sand and clay. Firing takes from two to six weeks.

6.4. Technological Perspectives

In response to fuel price increases during the 1970s and 1980s, brickmakers improved the fuel efficiency of their kilns. They achieved this with better kiln designs, reduced leakage, and added insulation.

6.4.1. Roller Kiln

A new technology is the rapid firing technology for bricks and tiles, called the roller kiln. In the rapid firing process, the clay is prepared dry with appropriate additives to maintain the forming and baking characteristics required. The amount of water is thus reduced to 6-8% (compared to 18-20% in the current tunnel kiln process). The fired products are transported on refractory rollers, rather than on lorries. Tunnel kilns have a production cycle of 75-140 hours. A roller kiln makes it possible to reduce the heating time (to approximately 8-9 hours) and use shorter firing curves. The flue gas volumes in the roller kilns are lower, compared to the tunnel kiln, hence reducing the heat losses. This reduces not only the heat demand, but also the power consumption for the air circulation.

The technology is in the demonstration phase for some products and at an advanced R&D stage for others. The current deployment of the technology is small with about 10-15 installations across the European Union.

Market penetration in the EU, after demonstration of the roller kiln, will depend strongly on the competition of modern tunnel kilns and on the investment budgets of the companies. In principal approximately 90-95% of the bricks can be produced in roller kilns. The remainder of the bricks are produced in specialised production facilities (bricks for restoration purposes etc.).

The roller kiln is now demonstrated in the ceramic industries (sanitary ware) and in brick manufacture. In The Netherlands a roller kiln is demonstrated for sanitary ware. The kiln reduced the energy consumption by 60% relative to the previous used tunnel kiln, and reduced the specific energy consumption to 4.15 GJ/tonne product. The performance can even be further improved by heat recovery from the flue gases. The technology is under investigation for more massive products like tiles and bricks. In Italy a new plant produces 50,000 lightened and specially shaped bricks per day using the rapid firing technology. The plant is designed to consume 1.4 GJ/tonne. Initially it consumed 1.6 GJ/tonne and the performance has been improving considerably since its installation.

The EU-report (THERMIE programme) states energy saving with firing of roller kilns versus tunnel kilns between 10 and 20%. The electricity savings are estimated up to 20%.

Investment costs for a roller kiln with a capacity of 50,000 tonnes/year are estimated at 400,000 euro (16 million BF), while the maintenance costs are lower for a roller kiln. However, the total production costs are assumed to be equivalent to those of a modern tunnel kiln. For bricks two plants are in operation in the EU (Italy and Germany) while two are constructed in other countries (Indonesia and Mexico)[24].

6.5. Current and future technology and capacity

Table 24 shows the expected production capacity evolution of the Belgian bricks industry estimated from the bricks production evolution.

	1995	2000	2005	2010
Capacity (million tonnes)	1,5	1,5	1,5	1,5

Table 24.- Bricks production capacity

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[24] ATLAS Project

Installed capacity: 1500 kt/a perforated bricks[25] .

The bricks and tiles production sector is characterised by a large number of SMEs.

The Belgian building materials group “Koramic Building Products” is one of the leading European building materials manufacturers. Next to its core business the production of roofing systems (mainly roof tiles among which the famous Belgian Pottelberg tile), the Group also produces building materials such as bricks (number 1 in the world), floor- and wall tiles, adhesives, tubes and pipes. Koramic is active in 26 countries, with participation in more than 250 production units that employ more than 12,000 people.

Koramic Roofing Systems is one of the leading European producers of clay roof tiles and occupies also an important position in the market of rolled zinc.

6.6. Environmental Perspectives

6.6.1. GHG emissions

The production of bricks and tiles is made from quarried clay and other materials that are formed, dried and subsequently baked at high temperatures in kilns and furnaces. The firing process in brick and tile production use much energy. Other main energy consuming unit operations in production are drying and clay preparation. The total energy consumption depends on the moisture contents, on the temperature ranges of drying and firing, on the brick type (massive, hollow) and the type of clay used. Thinner products like roof tiles are produced with relatively less specific heat consumption compared to bricks.

Table 25 shows energy consumption and CO2 emissions by technology for producing one tonne of bricks.

Manufacturing	Combustion GJ/t	Electricity GJ/t	Process t CO2/t brick	CO2 emissions t/t brick
Tunnel kiln	2,3	0,25	----	0,16
Roller kiln	1,60	0,10	___	0,10

Table 25.- CO2 emissions by technology in bricks manufacturing
Source: IW, MATTER and EC Thermie Programme

The average specific energy consumption for bricks production is estimated at 2.8 GJ/tonne, but may vary per product type.

The heat consumption in the kilns is 57% and the electricity consumption is 25% of respectively total heat and total electricity consumption of the brick production. The average energy consumption of total production is 1,94 GJ/t and 43 kWh/t.[26].

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[25] European Minerals Yearbook.

[26] EU-report "Market study into the introduction of roller kiln in the brick and heavy clay industry". THERMIE Programme, December 1995, IDAE.

6.6.2. GHG emissions mitigation

IPCC list of improvement options applied to the bricks/tiles manufacturing industry:

6.6.2.1. Increased energy efficiency and cleaner technologies

Roller kiln eliminates the use of the kiln car and allows faster firing than by the conventional tunnel kiln, requiring less fuel and contributing to energy conservation. In addition, due to the reduced moisture content less energy is needed in the drying section.

6.6.2.2. Dematerialization and materials substitution

The brick type determines the energy requirements.

Perforations reduce the weight per brick. However, the mortar requirements increase if the perforation volume is increased in a vertical direction.

6.6.3. Other environmental impacts

Various phases of the brick process generate particulate emissions. The main source of dust is the materials handling process, which includes pulverising, screening, and storing the raw material.

Manufacturers of bricks often use sintering to drive off entrained volatile matter from the clay. Because it is desirable for the clay to contain a sufficient amount of volatile matter so that the resultant aggregate will not be too heavy, it is sometimes necessary to mix the clay with finely pulverised coke prior to sintering. The addition of pulverised coke presents an emissions problem because sintering coke-impregnated clay produces more particulate emissions than the sintering of natural clay.

Brick production tunnel kiln

Energy Inputs		*Source*
Electricity	0,25 GJ	IW
Natural gas	2,26 GJ	IW
Gas oil	0,04 GJ	IW
Material Outputs		
Brick	1 t	IW

Brick production roller kiln

Energy Inputs		
Electricity	0,10 GJ	MATTER
Natural gas	1,60 GJ	MATTER
Material Outputs		
Brick	1 t	MATTER

Table 26.- Material and energy input/output in brick manufacturing by technology

7. THE WOOD PRODUCTS INDUSTRY

7.1. Wood products production and consumption in Belgium

Belgium has a total forest area and other wooded land of 620000 ha (0,06 ha per capita) considered exploitable, accounting for about 23% of its total area. Forestland is 46% publicly-owned and 54 % privately-owned, playing local communities and important role as forest owners (34%).

Since wood availability is fundamental to the industry, the forest-based industries, together with the forest owners, have made substancials efforts to ensure the development of the whole forestry sector. As a result, the Belgium forest cover and growing stock have increased over the last 100 years and more than 54% since 1866.

Employment in the principal wood production categories totalled approximately 60000 people, from which 3500 people work in the sawmill industry.

The Belgian sawmilling industry consists of mills spread all over Belgium. The production of sawn wood in Belgium from softwood is higher than the production from hardwood.

Wood product	Production (1000 m3)	Imports (1000 m3)	Exports (1000 m3)	Consumption (1000 m3)
Wood in the rough	3723	2330	920	5134
Sawnwood	1206	2071	547	2730
Panels	2528	734	1887	1375

Table 27.- Wood products production and consumption in Belgium-Luxembourg in 1996
Source: UN/ECE Timber Database

7.2. Product characterisation

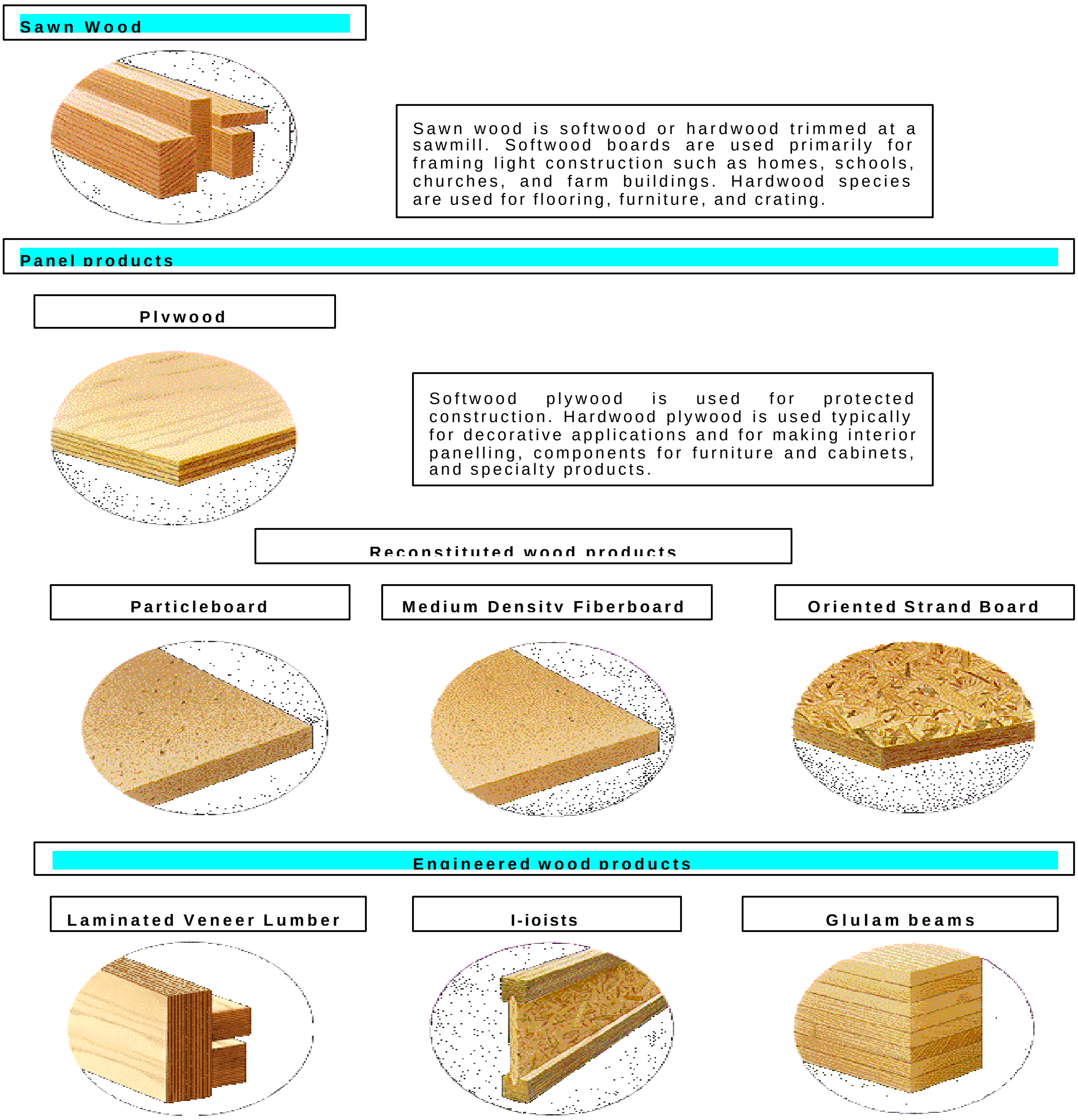
The main end use market for the industry's products is the new construction and remodeling sectors.

The sawn wood and wood products industry includes establishments engaged in cutting timber and pulpwood such as sawmills and plywood mills and establishments engaged in manufacturing finished articles made entirely or mainly of wood or related materials such as reconstituted wood panel products manufacturers.

Veneer is a thin sheet of wood peeled or sliced from blocks of sawn wood called flitches or logs. Veneer is glued together to form plywood. Softwood plywood is generally made with relatively thick faces and with exterior or intermediate glue. Hardwood plywood is made with thin face veneers. Because of its nature and the use of decorative thin face veneers, the glues used for hardwood plywood tend to be colourless or light in colour so as not to discolour the surfaces if the adhesive bleeds into and through the thin faces. While most hardwood plywood is all veneer, some is made with particleboard and medium density fiberboard core.

In construction and building, plywoods are mainly used in lining and panelling interior and exterior walls, supporting construction, concrete formwork and shuttering, working platforms of scaffoldings, facades and floors.

Glued engineered wood products are manufactured by bonding together wood strands, veneers, sawn wood or other forms of wood fiber to produce a lager and integral composite unit with structural performance characteristics.



Sawn wood is softwood or hardwood trimmed at a sawmill. Softwood boards are used primarily for framing light construction such as homes, schools, churches, and farm buildings. Hardwood species are used for flooring, furniture, and crating.

Softwood plywood is used for protected construction. Hardwood plywood is used typically for decorative applications and for making interior panelling, components for furniture and cabinets, and specialty products.

Figure 9.- Wood products
Source graphics: Willamette Industries (USA)

7.3. Main production routes in the wood industry

The wood industry processes are divided into five general groups: logging timber, producing sawn wood, panel products (including veneer and plywood and reconstituted wood panel products), engineered sawn wood and wood preserving.

7.3.1. Logging timber

Timber harvesting may be accomplished by either manual or mechanical means. However, the traditional methods of hand sawing are almost never used.

7.3.2. Producing sawn wood

Logs are delivered to sawmills from the forest and stored in ponds or on land. If stored on land, the logs are usually sprayed with water to keep them moist and prevent cracking. The raw logs are debarked and then cut into cants (partially cut sawn wood), which are trimmed into raw sawn wood. As the logs are debarked, bark is used as fuel for boilers or sold as mulch. Shavings, sawdust, and chips can also be used at paper mills and reconstituted wood panel manufacturing plants.

Most sawn wood is dried to a specific moisture content (conditioned) through air or kiln drying. Air drying, which entails stickering (spacing) and stacking the cut sawn wood in open storage areas, usually requires several months to a few years. Kiln drying is more time efficient because it uses controlled air flow within a vented closed chamber to quickly dry the sawn wood. Whether sawn wood is air- or kiln-dried depends upon variables such as the moisture content of the species and the humidity.

Sawmills frequently perform surface protection operations to protect sawn wood against sapstaining that may occur during temporary storage. The most popular surface protectant currently used to treat sawn wood is a solution composed of 3-iodo-z-propynyl butyl carbamate (IPBC), didecyl dimethyl ammonium chloride (DDAC), and inert ingredients diluted with water. Three major processes are used by sawmills to apply surface protectant to wood: the batch dip process, the continuous spray process, and the continuous green chain process.

7.3.3. Panel products

7.3.3.1. Hardwood Veneer and Softwood Veneer and Plywood

Logs received at the plant are debarked and cut. Almost all hardwood and many softwood blocks are heated prior to cutting or peeling the veneer to soften the wood. The cut logs are heated by steaming, soaking in hot water, spraying with hot water, or combinations of these methods.

The major methods for producing veneer are slicing and peeling. The majority of veneer is produced by peeling (rotary cutting) on a veneer lathe into sheets of uniform thickness. Slicing is used to produce hardwood decorative veneers and is seldom used with softwood.

After the veneer is peeled and clipped, it must be dried. Two types of dryers are used in softwood veneer mills: roller resistant dryers, heated by forced air; and platen dryers, heated by steam. In older roller dryers, also still widely used for hardwood veneer, air is circulated through a zone parallel to the veneer. Plants built in recent years use jet dryers (also called impingement dryers) that direct a current of air, through small tubes on the surface of the veneer.

Veneer dryers may be heated indirectly with steam or directly by the combustion gases of a gas- or wood-fired burner.

From the dryer, the sheets of veneer travel to a glue application station. Various adhesive application systems are used including hard rolls, sponge rolls, curtain coaters, sprayers, and foam extruders. The most common application for softwood plywood is an air or airless spray system. Roller applications are most common in the manufacture of hardwood plywood.

The phenol-formaldehyde (PF) typical in softwood plywood manufacturing and urea-formaldehyde (UF) adhesions typically used in hardwood plywood are made from resins. At the mills, the resins are combined with extenders, fillers, catalysts, and caustic to make a glue mixture. The addition of these ingredients modifies the viscosity of the adhesive and allows it to be compatible with the glue application method (curtain, roll, spray, foam); allows for better adhesive distribution; increases the cure rate; and lowers cost.

Following the application of glue, the panels must be pressed. At this point, resin is heated to the temperature required for the glue to bond. Most plywood plants prepress the panels in a cold press at lower pressure prior to final pressing in the hot press. This allows the wet adhesive to «tack » the veneers together, permits easier loading of the hot-press, and prevents shifting of the veneers during loading. Pressing is usually performed in multiopening presses.

After pressing, stationary circular saws trim up to one inch from each side of the pressed plywood to produce square-edged sheets. Almost all hardwood plywood production is sanded. The plywood trim and sawdust are burned as fuel or sold to reconstituted panel plants.

7.3.3.2. Reconstituted wood products

Reconstituted wood products, such as particleboard (PB), medium density fiberboard (MDF), hardboard (HB), and oriented strand board (OSB), is composed of furnish, or raw wood, that is combined with resins and other additives and formed into a mat, which is then pressed into a board. The manufacturing processes of these boards differ, as do the raw materials used. For example, the furnish (raw materials) used for particleboard consists of finely ground wood particles of various sizes, while OSB is manufactured using specially-prepared strands of wood. In general, the manufacturing processes involve wood size reduction followed by drying (except for wet process boards), adhesive application and pressing at elevated temperatures.

Particleboard is a panel product made from wood particles of various sizes that are bonded together with a synthetic resin such as urea-formaldehyde (UF). The raw materials, or « furnish, » that are used to manufacture PB can be either green or dry wood residues. Wood residues include shavings, sawdust, sanderdust and plywood trim. They are ground into particles of varying sizes using flakers, mechanical refiners, and hammermills. The material may be screened prior to refining. The furnish is dried to a low moisture content (two to six percent) to allow for moisture that will be gained by the adding of resins and other additives during « blending. ». Dryer temperatures may be as high as 1100 - 1200°F with a wet furnish. However, dry planer shavings require that dryer temperatures be no higher than 500°F because the ignition point of dry wood is 446°F. Dry material is the predominant furnish in particleboard. The furnish is then blended with synthetic adhesives, wax, and other additives distributed via spray nozzles, simple tubes, or atomizers. Resin may be added as received (usually an aqueous solution); mixed with water, wax emulsion, catalyst, or other additives. Waxes are added to impart water repellency and dimensional stability to the boards upon wetting. Particles for PB are mixed with the additive in blenders with glue injection tubes in through which the furnish passes in seconds. The furnish and resin mixture is then formed into mats using a dry process. This procedure uses air or a mechanical system to distribute the furnish onto a moving caul (tray), belt, or screen.

Particleboard mats are often formed of layers of different sized particles, with the larger particles in the core, and the finer particles on the outside of the board. The mats are hot pressed to increase their density and to cure the resin. Primary finishing steps for all reconstituted wood panels include cooling or hot stacking, grading, trimming/cutting, and sanding. Cooling is important for UF-resin-cured boards since the resin degrades at high temperatures after curing. Boards bonded using PF resins may be hot-stacked to provide additional curing time. Secondary finishing steps include filling, painting, laminating, and edge finishing.

The uses for Medium Density Fiberboard (MDF) are similar to those of PB. The furnish used to manufacture MDF consists of the same type of green or dry wood residues used to manufacture PB and hardboard. Fibers and fiber bundels are generated by first steam-heating the wood, then passing it through a refiner. During this step the wood changes both chemically and physically; becoming less susceptible to the influences of moisture and less brittle as the lignin in the wood softens. This semi-plastic wood is then « rubbed » apart into fibers and fiber bundles in a refiner instead of being mechanically «broken » apart as in the PB manufacturing process. The blending process for MDF differs from that of PB in that it typically occurs before drying. After refining, the fibers are discharged through a valve known as the blowvalve into the blowline, a larger continuous chamber where the UF resins are mixed with the wood fiber. In the blowline, the fibers are sprayed with a resin which is injected from a line located either immediately after the blowvalve or anywhere along the blowline. Material is dried to an acceptable moisture content in a flash tube dryer at low temperatures after the blowline. If the blending is done mechanically, as in PB, it is done after the flash tube dryer. MDF is formed using a dry process which uses air to distribute the furnish in a random orientation onto a moving caul (tray), belt, or screen. The mats are then pressed using a multi-opening platen press or a continuous press. The boards are then cooled and finished like other reconstituted wood panels.

Hardboard is a higher-density version of MDF. There are three types of hardboard: wet, wet/dry, and dry process hardboard, each classified by their manufacturing processes. The furnish used to manufacture hardboard consists of the same green or dry process wood residues used to manufacture PB and MDF. The cooked semi-plastic furnish is « rubbed » apart into fiber bundles as in the MDF process. The fibers are all the same size, therefore, they need no screening. In the manufacture of wet, and wet/dry process hardboard, the furnish is not dried because the forming process uses water. Wet and wet/dry process hardboard mats are formed using a wet process in which fibers are mixed with water and Phenol Formaldehyde adhesive and then metered onto a wire screen. Water is drained away with the aid of suction applied to the underside of the wire. The fiber mat, along with the supporting wire, is moved to a prepress where excess water is squeezed out. Wet/dry process hardboard is dried in an oven before being hot pressed. In the manufacture of dry process hardboard, the furnish is dried using dryers typical of the reconstituted wood panel industry. As with MDF, the hardboard fibers are discharged through a blowvalve into a blowline after refining. Dry process hardboard mats are formed using a process similar to that of MDF and PB in which air is used to distribute the furnish in a random orientation onto a moving caul (tray), belt, or screen. All reconstituted wood panels are hot pressed to increase their density and to cure the resin.

The furnish used to manufacture Oriented Strandboard (OSB) is specially flaked from roundwood. Logs entering OSB plants are debarked and sent to a strander which slices them. The strands are then conveyed to a storage bin to await processing through the dryers. The strands are dried to a low moisture content. The strands are then blended with additives in blenders in which the furnish passes through in several minutes. They are sprayed with either PF or MDI (Methylenediphenyl diisocyanate) resin and either liquid or emulsified paraffin wax. The tumbling action of the strands through the blender drums allows the strands to mix thoroughly with the resin and wax. OSB is formed by a dry process, which uses air to distribute the furnish. OSB is produced by deliberate mechanical lining-up of the strands. In the mechanical orientation processes, mats are produced by dropping long slender flakes between parallel plates or disks onto a moving caul (tray), belt, or screen. The boards are then hot pressed and finished.

7.3.4. Engineered sawn wood

Several composite wood products, intended as substitutes for sawn wood as well as other structural materials, are now on the market. Parallel strand sawn wood, made from long strands of veneer, is extruded with PF resin into various cross sections and widths. Parallel laminated veneer, or laminated veneer lumber (LVL), is constructed of veneers that are bonded together with phenol-formaldehyde (PF) adhesive resin to form a laminate. The veneers are layered with the wood grain along the long axis of the beam. Another application of LVL is in the construction of wood « I » joists (a small beam that resembles the letter « I »). LVL is used to construct the top and bottom (flanges) of the joist and OSB or plywood is used to construct the center (web).

Glulam beams are also emerging as a substitute for sawn wood. Glulam is short for glued-laminated structural timber – large beams fabricated by bonding layers of specially-selected sawn wood with Resorcinol or Resorcinol/PF adhesives and timber. Glulam timbers are used with structural wood panels for many types of heavy timber construction.

Most of the engineered sawn wood products are used as substitutes for structural softwood of large sizes and in applications where uniform strength is essential. I-beams, however, are finding wide application, with extensive use as floor joists and beams for various structures. There are several advantages of composite sawn wood when compared with sawn softwood. First, these products allow production of large sizes of sawn wood from small, low-grade logs. Normally, relatively large and high-grade sawlogs are needed for production of sawn wood of this size. Second, composite sawn wood compares advantageously to solid sawn wood in terms of both uniformity of quality and straightness. While the quality of sawn wood is determined to a great extent by the raw material, the quality of the reconstituted is dependent upon the manufacturing process. It is likely, however, that use of composite sawn wood will increase in the future.

7.3.5. Wood Preserving

Wood is treated with preservatives to protect it from mechanical, physical, and chemical influences. Preserved wood is used primarily in the construction, railroad, and utilities industries to prevent rotting when wood is exposed to damp soil, standing water, or rain, and as protection against termites and marine borers. The most common preservatives include water-borne inorganics like chromated copper arsenate and ammoniacal copper zinc arsenate, and oil-borne organics like pentachlorophenol and creosote.

Creosote, pentachlorophenol, and inorganic wood preservatives are all applied using similar processes. Most wood preservation is performed using pressure treatment processes. A limited quantity of wood is preserved using non-pressure treatment processes in which the preservative is allowed to diffuse into the wood. This process is used with some oil-borne preservatives, but not with waterborne inorganics.

Wood is usually conditioned in the open air or conditioned in the cylinder (retort) in which the pressure treatment is performed. The sawn wood is sometimes incised to increase preservative penetration. Open air drying is typically used to prepare large stock for treatment with oil-borne preservatives. Other methods for conditioning wood prior to treatment with oil-borne preservatives include steaming, heating, and vapour drying. Kiln drying is used primarily for water-borne treatment.

After the moisture content of the wood has been reduced, the wood is preserved using either non-pressure or pressure methods. Non-pressure processes include brushing, spraying, dipping, soaking, and thermal processes.

There are two basic types of pressure treatment processes, distinguished by the sequence in which vacuum and pressure are applied. These are «empty-cell » and «full-cell » or « modified full cell » processes. The terms « empty » and « full » are measures of the level of preservative retained by the wood cells.

« Empty-cell » processes obtain relatively deep penetration with limited absorption of preservative. In the Reuping empty-cell process, air pressure is applied to the wood as preservative is pumped into the treating cylinder. Once the desired level of retention has been achieved, the unused preservative is drained off and the excess preservative is vacuum pumped away from the wood. The process is the same in the Lowry empty-cell process, except no initial pressure is applied. In both processes, air compressed in the wood drives out part of the preservative absorbed during the pressure period when pressure is released. The second method, know as the « full-cell » (Bethel) process, results in higher retention of preservative but limited penetration compared to the empty-cell process. The full-cell or modified full cell procedures are used with both oil- and water-borne preservatives. A vacuum is created in the treating cylinder and preservative is pumped in without breaking the vacuum. Once full, hydrostatic or pneumatic pressure is applied until the wood will retain no more preservative. A final vacuum may then be applied to remove excess preservative, which is returned to the work tank for reuse. The treated wood is removed from the cylinder and placed on a drip pad where it remains until dripping has ceased.

7.4. Technological Perspectives

The imminent challenges for forestry policy at both the European and international level include the implementation of sustainable forestry, the role played by forests in controlling climate change and the promotion of credible forest certification systems.

7.5. Current and future technology and capacity

Woodworking industries supply basic products such as sawn goods, wood-based panels and builders' carpentry for construction, internal decoration and furniture.

7.5.1. Sawmills

The sawmilling industry is characterised by a large number of mills with a relative small production capacity.

One aspect of the first wood transformation in Belgium to be noted is the uneven distribution of the drying capacity between Wallonia and Flanders. While Flemish wood sector is well equipped with drying installations, the other region is characterised by a low capacity. The very recent years, the Walloon Government and the walloon wood sector has become conscious of the need to improve this situation. A 50 millions BEF budget has been made available by the public authorities to support this objective.

For coniferous wood drying represents an average cost around 1000 BEF/m^3 sawn wood.

7.5.2. Wood panels industry

The particle board industry is the largest industry compared to the other industries that produce wood based panels. The average plant sizes are much larger than sawmills.

- Spanolux S.A. manufactures MDF panels.

- Sovalbois Exploitation SA (Société de Valorisation du Bois) recycles rough timber, planks, laths and sawdust to produce 95000 m3 of particleboard panels per year. Sovalbois sells MDF and OSB panels.

7.6. Environmental Perspectives

Sustainable development has become a key priority for the forest-based and related industries starting from sustainable forest management. But it also means improved recovery at all production and consumption levels: heat recovery from the barks of the trees and all the other process inherent to recovery and recycling activities.

Recovery starts from the beginning of the industrial process, debarking, through the different process stages where wood residues, wooden chips, an other leftovers from each processing stage are either inserted into production processes or used in energy generation. Energy generation from wood products has also the advantage of emitting into the atmosphere only the CO2 once trapped in the product. Thus, it does not generate a net increase in the atmospheric CO2 balance.

7.6.1. GHG emissions

Consumption of energy is low in the wood products industry and there is little need for the use of fossil fuels.

The energy consumption of the manufacturers, including cutting and transport of the timber, amounts to a total of 1725 MJ or 480 kWh per m³ timber[27].

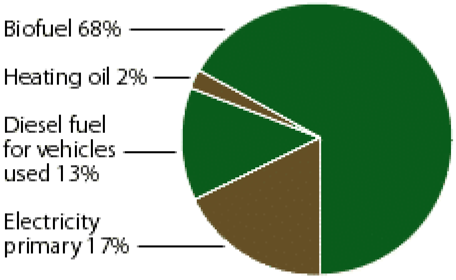


Figure 10.- Proportion of energy consumption of the manufacturers, including cutting and transport of the timber.

The production of sawn timber does not require much energy, and there is little need for the use of fossil fuels.

It is the kiln drying process which uses most of the energy involved in the production process. The energy required is often produced by the sawmills themselves by burning the by-products, such as bark and sawdust.

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[27] Nordic Timber Council

Because of the drying, no chemicals are needed. Kiln drying increases the end-use possibilities, and the value of sawn timber.

Forest and their products have the capacity to store vast amounts of carbon (1 tonne of CO2 in 1 cubic metre of timber)[28]. Wood products have the advantage of emitting into the atmosphere only the CO2 once trapped in the product. Thus, it does not generate a net increase in the atmospheric CO2 balance. *To illustrate this, the Dobris report points out that European Forests contain about 2,8 Gt of carbon in trees and litter, plus 3-4 Gt of carbon in forest soil. 2,8 Gt of carbon is the amount of carbon emitted from fossil fuels in the European Union about 4 years.*

Hardwood drying uses more energy than softwood drying.

CO2 emissions in the life cycle related to one cubic metre of timber[29] are 20000 g/m^3.

The tables bellow show the use of resources (timber, water, energy and various materials) in the lifecycle of one cubic metre of timber produced and transported.

Timber including bark	1.2 fm³ *

Table 28.- Primary raw-material consumption in 1 m^3 timber production

*0.2 fm³ of chips and bark is needed for the generation of heat for the producer's own requirements.

Water for sprinkling of roundwood, six month per year	2.3m³

Table 29.- Use of resources in 1 m^3 timber production

Oil	40
Diesel fuel for transport vehicles	230
Biofuel	1 170
Electric power, primary*	285
Total	**1 725**

Table 30.- Energy Consumption [MJ] in 1 m^3 timber production

* Purchased or converted into consumption of primary energy. The conversion factor used is 1.0 for Norwegian hydroelectric power and1/0.54 for Swedish electricity.

Process oils, lubricant and hydraulic fluid	0.1-0.4
Wood litter	2.3
Packaging including steel tape	0.8

Table 31.- Materials [kg] in 1 m^3 timber production

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[28] Source: CEI BOIS (Confederation Europeenne des industries du bois).

[29] Source: Nordic Timber Council.

7.6.2. GHG emissions mitigation

IPCC list of improvement options applied to the wood products industry:

7.6.2.1. Dematerialization and materials substitution

Many softwoods can not meet the durability criteria without environmentally problematic treatment with toxins. PLATO (Providing Lasting Advanced Timber Options) and wood acetylation are options to enhance the durability of softwoods.

More durable products, play a significant role in climate change, through the extension of the carbon sink effect of forests. Increased use of wood products can both stimulate the growth and carbon sequestration and increase the carbon storage effect, while decreasing the emissions through material substitution.

Engineered wood products (eg. Glulam) can serve as substitute for tropical hardwoods in case large wood dimensions are required.

7.6.3. Other environmental impacts

In timber production, there are minor emissions into the water, the soil and the air caused by the production of sawn timber. Emissions into the water are caused by sprinkling of stored timber during the summer half of the year. These emissions are reduced by reduction of timber stocks, and by climate-controlled sprinkling system. Waste bark and ashes mainly cause emission into the soil. Waste bark is more and more used to produce energy or as a fill for roads.

Ashes can be returned to the forest. This leads to lower environmental impact. Wood fibres and terpenes are released into the air during sawing and drying. The living forests also give off terpenes. Most of the residual wood from sawn wood production is reused as mulch, pulp, and furnish for some types of reconstituted wood panels; some is burned to produce steam or electricity. Boilers that burn wood waste produce: fly ash, carbon monoxide, and volatile organic compounds (VOCs). In addition, mills are potential sources of toxic manganese air emissions.

Two types of primary waste streams are typically generated during the surface protection phase of sawn wood production operations: process residuals and drippage. Spray operations tend to result in less excess formulation on the wood than either the dipping or green-chain operations.

In mills where chips or other furnish is generated on-site, operations such as debarking, sanding, chipping, grinding, and fiber separation generate particulate matter emissions in the form of sawdust and wood particulate matter.

Wastes generated in the gluing process include adhesive waste (typically overspray), and off-spec plywood.

Instead, air emissions from dryers and presses tend to be the principal environmental concern stemming from the production of wood products.

- Veneer dryers tend to release organic aerosols, gaseous organic compounds, and small amounts of wood fiber into the atmosphere. Organic aerosols and gaseous organic compounds, along with a small amount of wood fiber are found in the emissions from veneer impingement dryers. A mixture of organic compounds is driven from the green wood veneer as its water content is converted to steam in the drying process. Aerosols begin to form as the gaseous emissions are cooled below 302°F. These aerosols form visible emissions called blue haze. Direct-fired rotary drum dryers release emissions such as wood dust, combustion products, fly ash, and organic compounds evaporated from the extractable portion of the wood. Steam-heated and natural gas-filled dryers will have no fly ash. Emissions from the rotating drum wood chip dryers used in reconstituted wood panel plants are composed of wood dust, condensable hydrocarbons, fly ash, organic compounds evaporated from the extractable portion of the wood, and may include products of combustion such as CO, CO2, and NOx if direct-fired units are used. The organic portion of industry emissions includes terpenes, resins and fatty acids, and combustion and pyrolysis products such as methanol, acetic acid, ethanol, formaldehyde, and furfural. The condensable hydrocarbons and a portion of the VOCs leave the dryer stack as vapour but condense at normal atmospheric temperatures to form liquid particles that create the blue haze. Both the VOCs and the liquid organic mist are combustion products and compounds evaporated from the wood. Quantities emitted are dependent on wood species, dryer temperature, and fuel used. One significant cause of blue haze is overloading a dryer by attempting to remove too much moisture within a given time. Overloading results in the introduction of green material to a high-temperature flame or gas stream causing a thermal shock that results in a rapid and excessive volatilising of hydrocarbons that condense upon release to ambient air, causing the characteristic blue haze. Another factor affecting the composition of the effluent from rotary drum dryers is inlet dryer temperatures. The type of wood species burned also affects the composition of the effluent from rotary drum dryers.

- Emissions from hot presses consist primarily of condensable organics. When the press opens, vapours that may include resin ingredients such as formaldehyde, phenol, MDI, and other organic compounds are released to the atmosphere through vents in the roof above the press. Formaldehyde emitted through press vents during pressing and board cooling operations is dependent upon the amount of excess formaldehyde in the resin as well as press temperature and cycle time. Other variables include application rates, process rates, and the nature of the specific resin formations. Higher press temperatures generally result in higher formaldehyde emissions.

Typical air emissions sources in the wood preserving process are volatilisation of organic chemicals during wastewater evaporation, vapours released from the treating cylinder during unloading and charging operations, and emissions from the vacuum vent during the treating cycle. Aerosols and vapours may be released to ambient air.

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Sawn wood production

Material Inputs		*Source*
Timber	1,82 t	MATTER
Energy Inputs		
Electricity	1,2 GJ	MATTER
LT steam	3,6 GJ	MATTER
Material Outputs		
Sawn wood	1 t	MATTER
Sawn timber waste	0,82 t	MATTER

Chipboard production

Material Inputs		
Sawn timber waste	0,9 t	MATTER
Resins	0,1 t	MATTER
Energy Inputs		
LT steam	5 GJ	MATTER
Material Outputs		
Wood panel	1 t	MATTER

Table 32.- Material and energy input/output in wood products manufacturing

8. CONCLUSIONS

8.1. Materials Production Belgian System

The Table 33 synthesises the Industrial Energy Intensity and CO2 emissions by process and the potential efficient technologies by sector.

Industrial sector	Unit of material	Production routes in Belgium	Fuel combustion GJ/t	Electricity GJ/t	Process emissions t CO2/t	CO2 emissions t/t	New and emerging technologies
Iron and steel	Steel	79% blast furnace (BF)	10,1	1,46	0,24	1,7	**Ironmaking technologies**: ➢ Direct Smelting: COREX, CCF, SIDCOMET ➢ Direct Reduction: Midrex and Hyl **Casting technologies**: ➢ Thin slab casting ➢ Direct strip casting **Growth of EAF plants**
		21% electric-arc-furnace (EAF)	4,5	2,99	0,05	0,7	
Cement	Clinker	38% wet process	5,6	0,20	0,55	1,07	**Grinding process**: ➢ Roller mills **Growth of dry process with preheaters and precalciners** **Growth of blast furnace cement**
		21% dry process	3,3	0,25	0,55	0,87	
		41% dry process with precalciner	3,0	0,27	0,55	0,85	
Glass	Commercial flat glass	Fuel fired furnace	8,0	0,78	0,17	0,8	**Recuperative and regenerative preheating systems** **Increased glass recycling**
Bricks	Brick	Mainly continuous tunnel kiln	2,3	0,25	---	0,16	**Roller kiln**

Table 33.- Belgian industrial energy consumption and CO2 emissions per tonne of material

As indicates the Table 33, the steel industry is the major energy consumer. There are different production routes with substantially different energy intensities in which steel can be manufactured from iron ore (blast furnace route in integrated mills) or scrap (electric-arc-furnace route in minimills). Integrated mills produce pig iron, crude steel, and various forms and grades of refined and finished steel products. Major production steps used include concentrating and processing of iron ore, producing coke from coal, adding coke to iron ore to make iron, steelmaking, casting raw steel, and rolling, finishing, and milling steel products. As ironmaking is the most energy intensive, steel production from minimills, in which where the ironmaking and steelmaking steps are avoided, is generally much less energy and GHG intensive than steel production from an integrated steel mill. Concerning the product, high quality steels are examples of commodities that, because of the specifications that must be met in their manufacture, have above-average energy intensities in comparison to their broad product class. The GHG emissions from iron and steel production in integrated steel mills are mainly from the combustion of fossil fuels for energy (heat), the use of electrical energy, and the use of coal and lime as feedstock. These emissions are primarily of CO2, although very small amounts of CH4 and N2O may also be emitted. On average, one ton of steel produced in Belgium results in 1.5 tonnes of CO2 emissions. Regarding future technologies, there are substantial opportunities for energy saving in the integrated industry through the introduction of new technologies for smelt reduction and for near net shape casting. On the other hand, using scrap steel as a raw material reduces specific primary energy consumption in 1.8 GJ per tonne of steel produced.

In the cement sector, production involves treating limestone with heat to produce calcium oxide, or lime, and adding silicates to yield “clinker,” a raw cement. Clinker is then ground to size and blended to yield various cement-type products. The major end-uses of energy in this sector are process heat for producing clinker, plus motive power (usually supplied by electric or diesel motors) for grinding, moving, and blending raw materials, intermediate and final products. Clinker making is typically fueled with the least-expensive fuel readily available, often coal. Clinker production is the most energy intensive stage in the production of cement, and so “Portland”cements (with a high clinker content) tend to have high energy intensities. In fact, energy typically represents 30-40% of the production costs for cement. On average, one tonne of portland cement clinker produced in Belgium results in one tonne of CO2 being released into the atmosphere. About 60% is the result of calcination, and the other 40% is combustion products from the fossil fuels which supply the energy for calcination. There is the possibility to reduce energy use by changing from wet and semi-wet process to dry process. To reduce emissions, the cement industry can simply reduce the amount of clinker used to produce a unit of cement or concrete by replacing it with fly ash (a waste product from the coal fired utility industry) or blast furnace slag (a waste product from the production of steel). Fly ash and slag may be introduced either by a concrete producer as a replacement for portland cement, or inter-ground with clinker by the cement manufacturer to produce a composite cement. Either way results in a reduction in CO2 emissions: a 5% replacement of portland cement clinker with fly ash or blast furnace slag yields about a 5 million ton reduction in CO2 emissions resulting from the manufacture of clinker, 10% substitution yields a 10 million ton reduction, 15%, 15 million and so on.

Glass manufacture sector is very energy intensive, with energy accounting for some 20-25% of the total production costs. In general, 75% of the total energy is used in melting the raw materials. The glass is then formed using a variety of techniques dependent on the product. The three main sources for glass making are natural gas, fuel oil and electricity. The predominant fuel is fuel oil, but the use of natural gas is increasing. On average, one tonne of flat glass produced in Belgium results in 0.8 tonnes of CO2 being released into the atmosphere. Glass industry is very diverse, both in scale and the technologies used. Due to this diversity, it is inappropriate to specify energy efficient techniques. The use of cullet (recycled glass from the production line) reduce the energy consumption. In this way, most sectors of the glass industry utilise internal cullet (10-25% of the batch). Increasing 10% the cullet level in the batch has the potential to reduce in 2.5-3% the energy consumption. The composition of external cullet (recycled glass from consumer or external industrial sources) is less well defined and this limits its application as high final product quality requirements restrict the amount of external cullet to recycle. The significant use of external cullet is then restricted to the container (cullet use varies from 20 to 90%) and mineral wool sectors. In general, as recycling rates depend on the post-consumer glass collection, there is a potential to reduce CO2 emissions through implementation of appropriate collection systems for consumer glass.

Bricks industry is also an energy intensive sector, in which energy costs account for 25% of the production costs. Bricks manufacturing starts with the preparation of clay, which is then mixed with water to allow its extrusion. Pre-processing and forming are responsible for approximately 35 to 40% of the total electricity consumption, while drying and baking account for 65-60%. After shaping, the pieces are currently dried either in continuous tunnel dryers or in intermittent dryers, which leave them with the adequate moisture content to withstand the following baking phase. Firing is the major energy consuming step (heat) in the manufacturing process. On average, one ton of brick produced in Belgium results in 0.16 ton of CO2 emissions. There is a potential to reduce energy consumption through the introduction of a roller kiln to replace the continuous tunnel and intermittent kilns.

If reliance on fossil fuels and non-energy-efficient technologies continued, increasing use of energy in the industrial building materials sectors would result in vastly increased emissions of carbon dioxide. However, in general, increasing costs of energy have prompted the industry to improve its operational efficiency by investing in new technology. The iron and steel production, the cement industry, the manufacture of glass and lime industry belong to the group of process industries that generate carbon dioxide not only by fuel combustion and electricity consumption, but through the decomposition of carbonate raw materials. For this reason, targeted policies will be needed to accelerate the trend toward dematerialization and to encourage recycling and substitution of materials for those that are most emissions intensive.

8.2. Energy consumption versus CO2 emissions from products

An illustration on the orders of magnitude of the energy used in the manufacture and sale of several products used in housing, is presented in the Table 34.

	MJ/m3	Kg of crude oil equivalent/m3
Kiln-dried timber	1400	25
Normal-density concrete	1860	36
Reinforced concrete	3300	60
Clay bricks	3740	68
Particleboard	6600	120
Window glass	68000	1238
Iron beam girder	243000	4420

Table 34.- Energy used in the manufacture and sale of housing materials
Source: Office for Environmental Chemistry, Zurich 1998.

One cubic meter of normal-density concrete (including cement, transportation and placing) contains the energy equivalent to that represented by 36 kg of crude oil, more than the energy contained in kiln-dried timber, but less than the energy contained in clay bricks, particleboard, window glass and iron beam girder.

The Figure 11 indicates primary energy consumption and CO2 emissions by material unit of the most energy- and emissions-intensive Belgian building materials industries .

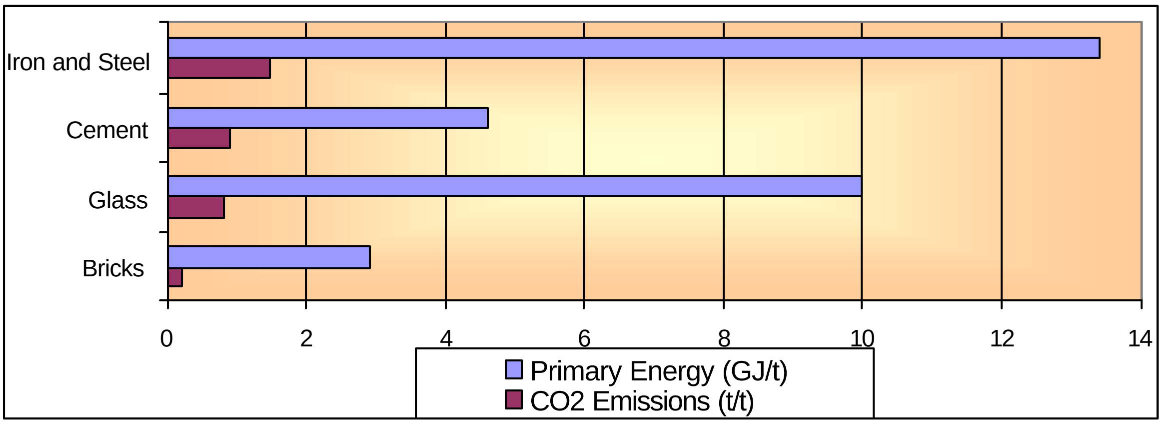

Figure 11.- Estimate Specific Primary Energy Consumption[30] (GJ/t material) and CO2 average emission factor (t CO2/t material).

While energy consumption is usually used as an indicator of environmental impacts, the Figure 11 shows that there is no a total direct proportionality between energy consumption and CO2 emissions. It is due to the fact that the amount of CO2 released into the atmosphere depend on the type of energy used (fuel or electricity) and the manufacturing materials used (process emissions). As we can presume from Figure 11, CO2 emission factor for concrete will be higher than for clay bricks and

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[30] The calculation of the primary energy consumption from electricity is based on an average generation efficiency 40%.

particleboard due to its cement content. For those reasons, it would be interesting to analyse the potential contribution of policies which focus on emissions by material consumed in relation to the existing policies which focus on emissions by energy consumed.

8.3. Materials production versus consumption

The Figure 12 shows the indirect CO2 emissions of some building materials related to Belgian production and consumption in 1998.

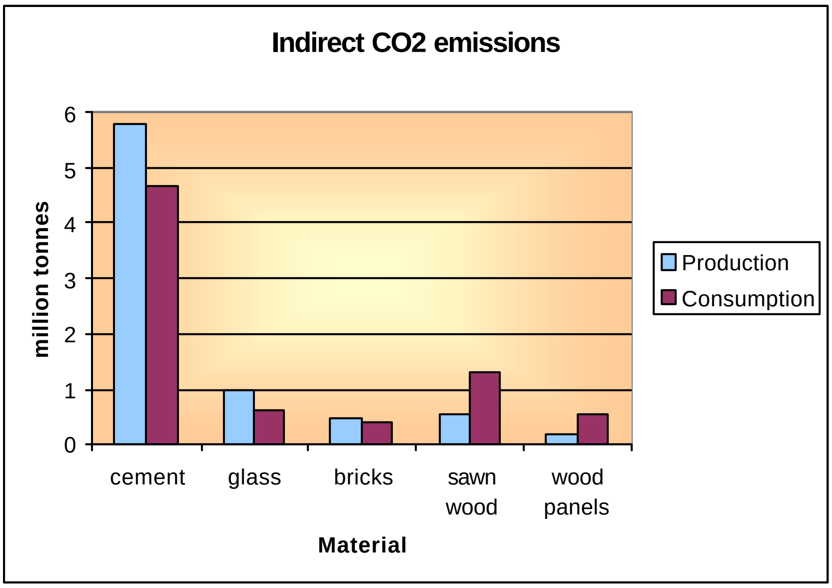

Figure 12.- Indirect CO2 emissions from Belgian production and consumption in 1998.

The Figure 12 gives an idea on the net imports and exports of CO2 emissions.

Although Belgium economy is almost self-sufficient concerning production and consumption of building materials, extractive flows (such as iron ore or oil) occur in other countries to support the production of the materials.

If environmental economic instruments are implemented in the production system rather than the consumption system (for instance, including environmental costs by material or product in the prices of commodities), the countries that benefit from using the materials or products, will not be the same as those paying the ecological costs of producing them. Furthermore, the environmental impacts which occur when any material enter or leave the national economy are not taken into account.

For these reasons, materials flows information considering the entire life cycle of products may point to the need for new policies.

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