CIPEC

BENCHMARKING ENERGY INTENSITY IN

THE CANADIAN STEEL INDUSTRY

PREPARED FOR CANADIAN STEEL PRODUCERS ASSOCIATION AND NATURAL RESOURCES CANADA

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1 INTRODUCTION

1. INTRODUCTION

The Canadian Steel Producers Association (CSPA) represents Canada's primary steel producers at the national level. One of Canada's largest industries, the steel sector generates annual sales of more than $11 billion, including $3 billion in exports, and directly employs about 35 000 workers. Energy efficiency is a priority for the CSPA, and Canadian steel producers have reduced specific energy consumption (megajoules [MJ] per tonne of steel shipped) by 23 percent since 1990.[1] In 2002, the CSPA agreed to undertake an energy benchmarking study with funding provided by the Industrial Programs Division of the Office of Energy Efficiency of Natural Resources Canada (NRCan) to identify further opportunities for energy reduction.

In addition to conservation of natural resources, there are compelling economic and environmental reasons for the nation's steel plants to comprehensively examine their energy consumption. Energy consumed by Canada's steel sector represents a sizeable component of the total cost of ironmaking and steelmaking operations. In addition, directly and indirectly, energy used in the steel sector is a contributor to carbon dioxide (CO_2) and other air emissions.

NRCan has been promoting more efficient use of energy in the Canadian economy for a number of years. The Canadian steel sector, through its involvement in the Canadian Industry Program for Energy Conservation (CIPEC), has participated actively in these energy initiatives.

1.1 Focus

The study focussed on the operations that produce steel and form it into hot rolled products. Twelve steel-producing plants (the participating plants) took part in the study – the four integrated plants and eight of the nine electric arc furnace (EAF) plants. The participating plants produced 14.9 million tonnes of steel in 2002, representing 97 percent of the steel produced in Canada that year.

The study involved a detailed inter-facility comparison of the energy consumed in steel production during 2002. Fifteen separate processes, each a production stage at two or more plants, were examined.

It was agreed with CSPA members that it was important to provide an international context for the detailed Canadian analysis. More specifically, it was deemed important to relate energy intensity (e.g. MJ per tonne of product) of the Canadian operations to that of the technology-based International Iron and Steel Institute (IISI) EcoTech plant. The IISI

[1] *Canadian Industry Program for Energy Conservation 2002/2003 Annual Report: Energy Ideas at Work*, pages 72–73 (oee.nrcan.gc.ca/Publications/infosource/Pub/cipec/AnnualReport02-03).

EcoTech Plant is a hypothetical plant that employs energy-saving technologies that are both commercially available and economically attractive. The concept of the EcoTech Plant is further described in Section 3.2, "Energy-Saving Technologies."

1.2 Objectives

The CSPA established the following objectives for this study:

1. Provide Canadian steel producers with a methodology to determine benchmarks for the efficiency with which energy is consumed at the plant level and at each stage of production.

2. Provide a list of technologies with the potential for achieving more efficient use of energy and enhancing the competitive position of the Canadian steel sector.

3. Provide a compilation of energy-intensity benchmarks and an analysis of the penetration of energy-efficient technologies for the CSPA member plants.

4. Provide a comparison of benchmarks and technology penetration between plants and against international technology-based benchmark levels, thereby allowing areas of potential improvement to be identified.

1.3 Layout of This Report

Chapter 2 provides some background information on energy use in Canada's steel sector.

Chapter 3 describes the methodology used to develop and apply energy-intensity benchmarks and to establish technology penetration.

Chapter 4 contains the principal findings.

Chapter 5 identifies the potential areas for energy savings based on the comparison of sector performance to the international technology-based benchmark level.

Chapter 6 lists the references used in the text.

Chapter 7 contains all figures, charts and tables.

Appendix A provides a list of EcoTech Technologies and energy-intensity and CO_2 emission-intensity indicators.

Appendix B provides a list of CO_2 emission factors.

2

ENERGY USE IN THE CANADIAN STEEL INDUSTRY

2. ENERGY USE IN THE CANADIAN STEEL INDUSTRY

2.1 Industry Background

Steel is produced at 13 plants in five provinces (Alberta, Saskatchewan, Manitoba, Ontario and Quebec). The industry is concentrated in Ontario, with six plants operating there.

Steel plants are divided into two general categories according to their major source of metal. Plants that produce steel from iron ore using the blast furnace and basic oxygen furnace (BOF) process are referred to as integrated plants. Plants that produce steel by melting steel scrap in the electric arc furnace (EAF) process are referred to as EAF plants. One Canadian integrated plant also uses the EAF process to produce a portion of its steel. One EAF plant has a direct reduction facility that produces "sponge" iron from iron ore, for conversion into steel in the EAF process. All four integrated steel plants are in Ontario.

2.2 Energy Use

The steel industry is a large industrial energy user in Canada, accounting for about 2.0 percent of the nation's primary energy consumption, which is 7.5 percent of Canada's industrial energy demand.[2,3] Year 2002 energy consumption for the Canadian steel sector is shown in Figure 2-1.

Steel is also highly recycled, with the recycling rate (defined as the amount of steel produced from salvaged obsolete steel products) being 40 percent in Canada. Recycling of steel strongly affects the energy performance of the sector as a whole, since steel produced from scrap requires considerably less energy than steel produced from iron ore. However, the supply of steel scrap is limited, so the steel demand must be satisfied with product made from both recycled scrap and iron ore. Also, the quality of steel produced from salvaged scrap is not satisfactory for some steel applications, due to impurities contained in scrap steel.

[2] Based on data contained in *NAICS Energy Consumption Report*, Statistics Canada, Cat. No. 57-003-XPB.

[3] Energy values are based on the higher heating values for fuels, which include the latent heat of vaporization of the water formed in the combustion process.
All electrical energy consumption has been converted to a unit of heat using a factor of 3600 megajoules per megawatt hour (MJ/MWh), which is the heat equivalent of the electrical energy consumed.

The production flow diagram for an EAF plant is shown in Figure 2-2, and the energy intensity for the participating EAF plants, for the year 2002, is shown in Figure 2-3. The production flow diagram for an integrated plant is shown in Figure 2-4, and the energy intensity for the participating integrated plants, for the year 2002, is shown in Figure 2-5.[4] These charts illustrate that the energy intensity of EAF plants is less than half that of the integrated plants. This comparison assumes that all electricity consumed was generated by fossil fuel power plants. In reality, a portion of the electricity consumed by Canadian steel plants is generated by nuclear or hydroelectric plants, so the amount of fossil fuel used to generate power for the steel plants would be less. The use of *actual* fossil fuel rates for power generation makes the inherently lower energy consumption of EAF plants even more favourable for overall energy efficiency and CO_2 intensity.

Energy expense for Canada's steel sector represents the second highest component (after labour) of the total cost of operation. Not surprisingly then, through its involvement in CIPEC and other initiatives, the steel sector has continually improved energy efficiency as a means of bettering its competitive position. Since 1990, the sector has reduced specific energy consumption (gigajoules per tonne of product) by 23 percent (see Figure 2-6) and has reduced CO_2 emissions by 20 percent.[5] This achievement was brought about largely by investments in new processes and energy-reducing technologies.

[4] All energy-intensity values in this report are based on the lower heating values for fuels, which do not include the latent heat of vaporization of the water formed in the combustion process.
All electrical-energy-intensity values in this report have been converted to fossil fuel input using a factor of 9200 MJ/MWh, which assumes 100 percent fossil fuel generation. The 9200 MJ/MWh factor was deemed to be representative of modern fossil fuel power generation in Europe by the International Iron and Steel Institute and the European Steelworks Energy Committee (see Chapter 6, references 1 and 2).

[5] *Canadian Industry Program for Energy Conservation 2002/2003 Annual Report: Energy Ideas at Work*, pages 72–73 (oee.nrcan.gc.ca/Publications/infosource/Pub/cipec/AnnualReport02-03).

3 METHODOLOGY

3. METHODOLOGY

3.1 Energy-Intensity Indicators

The steel industry worldwide has worked diligently to provide the knowledge and tools to enable steel plants to apply the energy-intensity indicator concept to their processes and plants. An in-depth understanding of the methodology can be found in reports produced by the IISI and the European Steelworks Energy Committee (ESEC)[6] associated with the organization Association Technique de la Sidérurgie (ATS). Knowledge of the methodology is not required to understand the results of the present study, but understanding the following aspects of the energy-intensity-indicator concept helps to ensure that the results are not misinterpreted or misapplied.

Energy-intensity benchmarking requires some type of indicator that is determined solely by the efficiency with which energy is consumed by the process or plant being evaluated. The indicator must be sensitive only to changes in technology and practice within the boundary of the particular process under review.

External differences, such as how purchased electrical energy is generated or how purchased oxygen is produced, will change the actual energy consumed per unit of steel product, but they will not change the efficiency with which energy is consumed in a given process. The energy-indicator methodology, therefore, assigns a fixed value to each manufactured energy stream (electricity, steam, oxygen) that enters or leaves the process being evaluated, and it applies the fixed values to the process at each plant under study.

For example, the fossil fuel energy consumed in generating electricity can range from 0 megajoules per megawatt hour (MJ/MWh) of electricity produced by a hydroelectric plant to 9200 MJ/MWh for electricity from a coal-fired power plant. The values for Canadian electrical utilities naturally fall within that general range. As the benchmark energy-intensity indicator in the present study, the fossil fuel energy value for electricity is fixed at the amount from a coal-fired plant – 9200 MJ/MWh. That value is applied to all plants, regardless of the actual value for electricity produced by their utility supplier.

The purchase and sale of intermediate products, such as coke, iron or steel slabs, also changes the specific energy consumption of a plant. Hence, the energy-intensity indicator must factor out sales and purchases and must consider all material to be produced and processed at the same energy intensity as the plant or process being evaluated.

The energy-intensity indicator is expressed in units of energy per unit of product (usually MJ per tonne). These are the same units as those used for specific energy consumption data. However, the values of the energy-intensity indicator must not be construed as specific

[6] Ibid. See Chapter 6, references 1 and 2.

energy consumptions. They will differ significantly from the specific energy consumption numbers reported by the steel plants to the various government programs, such as Canada's Climate Change Voluntary Challenge and Registry Inc. (VCR Inc.) [now CSA Climate Change, GHG Registries] and CIPEC. The energy-intensity indicator is different for the following reasons:

- The energy-intensity indicator is based on the lower (or net) heating values for the fuels consumed. The lower heating value does not include the latent heat of vaporization for the water formed in the combustion process. The lower heating value is used, to be consistent with the practice used by IISI and ESEC. All energy reporting in Canada is based on the higher (or gross) heating value for the fuels consumed. The higher heating value includes the latent heat of vaporization for the water formed in the combustion process.
- Process and plant boundaries are not necessarily the same.
- Fixed values are used for energy inputs that flow across the boundaries into the processes and plants.
- Energy associated with the sale and purchase of intermediate product is factored out in establishing the plant energy-intensity indicator.

The energy-intensity indicator must never be used in the context of actual plant energy consumption. The only legitimate use of the energy-intensity indicator is to compare the relative performance of identical or very similar processes or plants.

3.2 Energy-Saving Technologies

Since many energy-saving technologies are available to the steel industry, the energy-intensity indicator can be used to establish the potential for efficiency if one or more of these technologies are incorporated into existing processes or plants. This evaluation is accomplished by establishing the energy indicator for a reference process or plant that has the desired technologies in place and then using it as the benchmark against which the existing processes or plants are compared. Such benchmarks have been developed by IISI and are available for use as international guidelines for establishing the penetration of energy-saving technologies and the potential for further application.

The IISI EcoTech Plant,[7] a hypothetical plant that employs energy-saving technologies that are both commercially available and economically attractive (EcoTech Technologies), was selected as the benchmark for the present study. Whether the technologies are economically attractive depends on many factors, such as the energy price in a particular jurisdiction, the difficulty of retrofitting the technologies into existing process equipment and the incremental benefits if the technologies are only partially implemented. The economic attractiveness for a particular plant can be determined only by the plant considering the technology.

[7] See Chapter 6, reference 1.

There are few, if any, plants and processes operating with all of the IISI EcoTech Technologies in place. Therefore, the EcoTech energy-intensity values were established by extrapolating the energy-intensity indicators of operating processes and plants by the efficiency gains attributed to the additional energy-saving technologies required to complete the EcoTech Technology set. Admittedly, the EcoTech energy-intensity values are somewhat theoretical, and there is a lack of actual process and plant operating data to verify that they can be achieved in real life.

The IISI AllTech Plant[8] is a variant of the EcoTech Plant into which all proven energy-saving technologies have been incorporated, regardless of financial viability. Economic payback times in excess of 20 years are not uncommon for some AllTech Technologies. The AllTech Plant represents a severe standard of energy efficiency and, as such, was not an appropriate benchmark for this study. However, some AllTech Technologies are in place in the Canadian steel industry, which is an indication of their viability. AllTech Technologies that are utilized in the Canadian steel industry are included in the present study.

Of course, technology is only one factor that influences the energy efficiency of processes and plants. Some other factors include:

- Utilization of equipment: Energy efficiency increases if equipment is operated at or near design capacity. Although all plants strive for high equipment utilization, market and competitive pressure can result in equipment being idle or shut down for periods.
- Maintenance of equipment and technology: The 100 percent performance of technology requires material and labour for proper maintenance that, to a certain extent, is dictated by the economic condition of the industry.
- Product mix: The energy intensity will be higher for mills that produce a broad range of products because of material losses and energy consumption that occur during the period required to change over to the next product. Also, some grades of steel require more energy to produce.
- Climate: Energy intensity at Canadian mills will be greater because of the energy required to protect equipment and personnel from the harsh winter climate and to make up for greater process heat losses caused by low ambient temperatures.

Note that the effects of these other factors are not included in the EcoTech energy-intensity values.

For the present study, energy-efficient technologies were selected for each process investigated. The selected technologies include all of the EcoTech Technologies and other energy-saving technologies that either are in place at Canadian steel plants or have been recommended by previous studies for their potential for improving energy efficiency in the Canadian steel sector.[9] The technologies selected for each process and the penetration of the various technologies at each plant can be found in Chapter 4, "Results."

[8] See Chapter 6, reference 1.

[9] See Chapter 6, reference 3.

Some difficulties were encountered in using the EcoTech Plant as the benchmark for technology penetration and energy intensity. The difficulties, which pertain to the interpretation of the data and information in the IISI report,[10] include the following:

- Carbon in the metallic input and output to the processes was not always included in the energy balance. (It is in the present study.)
- The EcoTech Plant was not always defined by both technology and energy intensity. In some areas, such as reheating furnaces, energy-saving technologies are discussed but are not specifically identified as included in the EcoTech Plant. The technologies are, however, implied by the EcoTech Plant performance.
- Some EcoTech Technologies are defined in terms that are difficult or impossible to relate to actual plant performance or that have no universal meaning. (For example, defining recuperator performance in terms of efficiency instead of air preheat temperature.)
- In some cases, the energy-intensity indicators for the EcoTech Plant differ from the ones used by the ESEC.[11]

Consequently, the interpretation of the EcoTech Plant used in this study may differ from others.

Appendix A defines the interpretation of the EcoTech Plant used in this study. It provides for each process:

- the list of EcoTech Technologies
- the EcoTech energy-intensity indicator and CO_2 emission-intensity indicator, by energy type
- references to the IISI report for all EcoTech data and information

A table of the CO_2 emission factors, used to establish CO_2 intensity, is provided in Appendix B.

3.3 Applicability of Energy-Intensity Indicators to the Canadian Steel Sector

It must be emphasized that use of energy-intensity indicators is of value only for comparing identical or very similar processes. By properly applying the indicator, the operating practices and equipment technologies that produce the highest efficiency should become apparent. There is little value in comparing different processes that produce the same product. For example, liquid steel is produced by both the EAF process and the blast furnace/BOF process. The intrinsic differences between the two routes result in the EAF

[10] See Chapter 6, reference 1.
[11] See Chapter 6, reference 2.

process consuming about half as much energy as the BOF process. However, because the equipment used in the two situations is quite different, changing operating practices and technologies in one will not produce the same results in the other.

The processes and plants analysed in the present study were selected using the following criteria:

- They are applicable at two or more plants.
- They contain comparable process equipment.
- They have essentially the same material input and output streams.
- They have sufficient specific energy consumption to offer potential for noticeable reduction in energy use.

Two other processes not meeting the above criteria were also analysed:

1. One involves a direct reduction facility at an EAF plant. This facility is the only Canadian example of a number of alternate ironmaking technologies in use today. The facility uses Midrex Technologies Inc.'s MIDREX® Direct Reduction Process, the most widely accepted technology for producing direct reduced iron (DRI), which is natural gas based and requires the use of agglomerated iron ores.

2. The other is a cast-and-roll hot strip coil facility at an integrated plant. Liquid steel is cast into a thin slab (or thick strip) that is then hot rolled into hot strip coil products. The process is an alternative to the continuous casting and hot strip mill processes by eliminating two energy-intensive stages – the slab reheating furnace and the slab roughing or breakdown mill.

3.4 Data Collection

The calculation of energy-intensity indicators for the processes and plants requires the use of actual energy consumption and production data from a specific period. The present study is based on 2002 calendar year data that were obtained under a confidentiality agreement. The data for each process were collected using spreadsheet reporting forms based on the spreadsheets developed by ESEC.[12] The reporting forms calculate the energy-intensity indicators for each process as the data are entered. This enabled participating plants to instantly see their results and to question any results or data that seemed out of the expected range. A questionnaire was developed to collect additional information on the energy-saving technologies and practices that were in place for each process at each plant. The reporting forms were completed by personnel at each participating plant.

[12] See Chapter 6, reference 2.

Missing or questionable data were identified by the aggregation of the data for each process. The plants were contacted and additional and/or revised data were submitted. Dialogue continued with plant personnel to ensure that the information used was as complete and accurate as possible, although precision and certainty are difficult to evaluate because of different levels of metering at the various plants. Some of the data at some plants had to be estimated because of lack of metering. Where estimates of energy input allocation to processes were necessary, they were based on the relative energy requirements of the equipment, operating level and time.

3.5 Energy-Intensity Indicators for Processes

The energy efficiency indicators for each process at each participating plant were calculated by the "Reporting Form – Process Areas" spreadsheet.

3.6 Energy-Intensity Indicators for Plants

For energy benchmarking, plants are defined by their associated processes required to produce a *specific* product. Since the product could be an intermediate product or the final hot rolled product, more "Model" plants must be defined for energy benchmarking than the number of real-life plants participating in the present study. For example, three "Model" plants would be needed for a real EAF plant that produces both bar and rod:

- a plant consisting of the EAF and Continuous Casting processes for the production of billets, the intermediate product
- a plant consisting of the EAF, Continuous Casting and Bar Mill processes for the production of bar
- a plant consisting of the EAF, Continuous Casting and Rod Mill processes for the production of rod

The energy-intensity indicator for a plant is expressed in units of energy (MJ) per tonne of plant product.

The plant energy-intensity indicator is based on the energy-intensity indicator and the material input factor for each process in the operational stream. The energy-intensity indicators for the processes have been previously explained (see Section 3.5 "Energy-Intensity Indicators for Processes").

The material input factor is defined as the amount (tonnes) of input material that must be supplied to a process to produce a tonne of output. Since most processes lose material due to oxidation of the metal and the scrapping of material that is off specification, the input factor is often greater than one. Process input factors for each process are calculated from the material input and output data reported by the participating plants.

The processes required for a plant are linked by the material input factors to determine how much each process must produce for the plant to make one tonne of product. That number is then multiplied by the process energy-intensity indicator to establish the contribution that the process makes to the overall plant energy-intensity indicator. The plant energy-intensity indicator is the sum of the contributions of each process.

Figure 3.1 shows the operational stream for the EcoTech EAF Bar Plant and the EcoTech input factors that link the EAF, Continuous Casting and Bar Mill processes.

First, the amount of product that each process must make to produce a tonne of bar product is calculated by linking the input factors:

- tonnes of cast steel/tonne of bar = Bar Mill input factor = 1.031
- tonnes of liquid steel/tonne of bar = Bar Mill input factor × Continuous Casting input factor = 1.031 × 1.020 = 1.05

The plant energy-intensity indicator can then be calculated by adding the products of the amount of product required and the energy-intensity indicator for each process:

- Energy-intensity indicator for EcoTech EAF Bar Plant = Bar Plant energy-intensity indicator + (tonnes of cast steel/tonne of bar × Continuous Casting energy-intensity indicator) + (tonnes of liquid steel/tonne of bar × EAF energy-intensity indicator)

i.e. 2236 + (1.031 × 101) + (1.05 × 5154) = 7760 MJ/tonne of bar

Energy-intensity indicators for the production of intermediate products can be determined in a similar manner. For example, referring again to Figure 3-1, the energy-intensity indicator for the EcoTech EAF Billet Plant would be:

- Energy-intensity indicator for EcoTech EAF Billet Plant = Continuous Casting energy-intensity indicator + tonnes of liquid steel/tonne of billets × EAF energy-intensity indicator

i.e. 101 + (1.02 × 5154) = 5358 MJ/tonne of billets

Figure 3-2 illustrates how the processes for an integrated mill can be linked in a similar manner to obtain the “Model” EcoTech Integrated Hot Strip Coil Plant energy-intensity indicator. The integrated plant situation has the additional complication of the need to incorporate the plant utilities into the calculations. The plant energy-intensity indicator for the production facilities (peach boxes) is determined first. The overall plant energy-intensity indicator can then be determined by adding in the utilities’ energy consumptions (fuel gases to the boilers and flares) and credits (steam and electricity).

3.6.1 EAF Plant Energy-Intensity Indicators

The process areas studied at the EAF plants are shown as peach boxes in Figure 2-2. The electric arc furnace and continuous casting processes are separate production stages; but at most plants, they are treated as a single unit for energy metering and accounting. Therefore, in this study, arc furnace steelmaking and casting are combined.

The EAF plant consists of arc furnace steelmaking, casting and hot rolling operations. The latter can encompass one or more of four hot rolling processes – rod, bar, heavy section or hot strip rolling. These hot rolling processes differ according to the size and shape of the product made. Therefore, the EcoTech energy-intensity value is not the same for each process. To enable a meaningful and fair comparison of the plants, a separate "Model" plant energy-intensity indicator was determined for each of the four hot rolling processes.

3.6.2 Integrated Plant Energy-Intensity Indicators

The process areas studied at the integrated plants are shown in Figure 2-4. They are divided into two categories: production processes, which are shown as peach boxes; and plant utilities, which are shown as blue boxes. The division is required in order to achieve meaningful comparisons of plant performance. (Note that plant utilities in EAF plants are insignificant contributors to the overall plant energy balance because of the type of equipment used, e.g. no coke ovens, blast furnaces.)

The design and operation of integrated plant production processes are influenced by such priorities as productivity, cost, product quality and available raw materials. The utilities' processes are designed and operated to minimize energy cost. Recognition of this difference is important.

Plant utilities offer the following opportunities to reduce energy consumption and cost:

- distribution of plant by-product fuels (coke oven gas, blast furnace gas, basic oxygen furnace gas) for use in process heating applications, thus reducing or eliminating the need to purchase other fuels (natural gas, oil)
- conversion of plant by-product fuels into other energy forms (steam, electricity, compressed air) to meet the demands of the production processes and minimize the purchase of fuel and electricity
- sale of surplus or unusable energy (such as hot water for district heating)

Since the influence of the plant utilities on the overall integrated plant energy efficiency is immense, the effect of the utilities must be separated in order to isolate any energy efficiency gains in the production stream. Also, it is not possible to proportion the operation of the plant utilities to the individual production processes. For example, the flaring of unused plant by-product fuels depends on the demand for such fuels at other processes throughout the plant. The demand, in turn, is related to such aspects as the plant operating level and the capability of the power plant to convert the fuels to steam or electricity. Hence, the flaring of a given by-product fuel cannot be attributed to the process that produces that fuel.

In this study, a number of comparisons of plant performance were made. The energy efficiency of the production process stream was evaluated first for each intermediate product and then for the final hot rolled product *without* considering the effect of the plant utilities. The energy efficiency for the final hot rolled product was then established when the effects of the plant utilities were included.

For plants that operate two or more hot rolling processes (e.g. a hot strip mill, a cast-and-roll hot strip mill, a plate mill), the utilities (gas flares, water supply and treatment, and power plant) were allocated to each process in proportion to the quantity of hot rolled product that was produced by each process.

3.7 Energy-Intensity Indicators for Reheating Furnaces

Hot rolling processes are common to both EAF plants and integrated plants, so they can be compared at the process level. Reheating is the first operational stage in producing hot rolled products, with each hot rolling facility being equipped with one or more reheating furnaces to heat the semifinished steel to a uniform rolling temperature (1000 to 1250°C). Although the reheating furnace is not a separate process, it is studied separately in the present study for the following reasons:

- Reheating furnaces consume 60 percent or more of the total energy required for hot rolling.
- Most of the opportunities for applying energy-saving technologies in hot rolling are related to reheating furnaces.
- The penetration of energy-saving technologies for reheating furnaces cannot be evaluated at the overall hot rolling process level because some mills are equipped with two or more furnaces with different degrees of technical sophistication.

The energy-intensity indicators for each reheating furnace at each participating plant were calculated by the "Reporting Form – Reheating Furnaces" spreadsheet.

3.8 CO_2 Emission-Intensity Indicators

CO_2 emission-intensity indicators are derived by applying emission factors to the energy components of the energy-intensity indicators. Hence, the CO_2 emission-intensity indicator will depend not only on the process energy efficiency, but also on the energy resource consumed.

Emission factors for fuel (coal, carbon, coke, natural gas, oil, coke oven gas, blast furnace gas, BOF gas) are derived from the carbon content of the fuel. Participating plants were asked to report CO_2 emission factors for the fuels they consumed. Chemical analysis of fuels was also requested so that emission factors could be checked.

A significant amount of natural gas was consumed by all participating plants. Five plants from three provinces provided analyses of natural gas that yielded emission factors ranging from 55.77 to 56.06 g CO_2/MJ. Based on these data, an emission factor of 56 g CO_2/MJ was used for all reported natural gas consumption.

The emission factor for carbon is 3664 kg CO_2 per tonne of carbon.

There was considerable variation in the chemical analyses and CO_2 emission factors for the other fuels, especially the by-product fuel gases produced at the integrated plants. Therefore, plant-specific emission factors were used. Carbon balances were performed on the coke oven, blast furnace and BOF process areas at each integrated plant to ensure that the carbon content (and hence CO_2 emission factors) of their by-product fuel gases was reasonable.

Appendix B contains a complete table of CO_2 emission factors.

Fluxes are required in the ironmaking and steelmaking processes to separate impurities from the iron and steel. It is recognized that some materials when used as fluxes produce CO_2 emissions. Two examples are limestone, which is mostly calcium carbonate ($CaCO_3$), and dolomite, which is about 60 percent calcium carbonate and 40 percent magnesium carbonate ($MgCO_3$). When heated, calcium carbonate breaks down to form CO_2 and calcium oxide (CaO), which is a flux. Magnesium carbonate undergoes a similar reaction when heated to form CO_2 and magnesium oxide (MgO), which is also a flux. Burnt lime, another common term for calcium oxide, is produced by the calcination of limestone in rotary cement kilns. There are no CO_2 emissions from the ironmaking and steelmaking processes associated with the use of burnt lime as a flux. The CO_2 emission-intensity indicators in the present study **do not** include CO_2 emissions resulting from the use of limestone and dolomite.

The CO_2 emission-intensity indicator consists of three components: direct, utilities and external. Direct emission intensity considers emissions from sources within the process boundary. The utilities emission-intensity component takes into account emissions from facilities that supply utilities (steam, water, etc.) that are located outside of the process itself but are within the boundary of the plant. When benchmarking processes at different plants, standard emission factors are used for the utilities. This ensures the CO_2 emission-intensity indicators for the processes depend only on the technologies and practices within the process area boundary. When comparing plants, the actual emission factors for the production of the utilities at the plant being considered must be used because the facilities providing the utilities are within the plant boundary.

The external emission-intensity component in the present study is limited to the consumption of electricity used directly by the process and by the oxygen plant to produce any oxygen consumed by the process. Emissions associated with the production and delivery of other energy forms (natural gas, oil) and of raw materials (burnt lime, coal, iron ore, scrap, etc.) were not considered.

As explained in Section 3.1, "Energy-Intensity Indicators," the heat rate (energy value) for electricity is fixed at the amount for a coal-fired plant – 9200 MJ/MWh. That value is applied to all plants, regardless of the actual value for electricity produced by their utility supplier. To be consistent, the CO_2 emission factor used to calculate external CO_2 emission-intensity indicators is 856 kg/MWh. By using these factors, the results are comparable with the IISI and ESEC benchmarking practice. These factors are also considered to represent the marginal emission value. (The marginal emission value is the change in emissions that would occur if electricity demand were increased or decreased.) This assumption would be valid for jurisdictions that have modern coal-fired plants in operation or that have grid connections to jurisdictions that use coal-fired plants.

It must be emphasized that for benchmarking, the same factors for electrical energy and CO_2 emissions must be applied to all plants, regardless of the actual value for electricity produced by their utility supplier. All Canadian jurisdictions generate electrical energy with some facilities other than coal-fired plants. Therefore, the average heat rate and CO_2 emission factor for the various generation facilities in any Canadian jurisdiction will be much lower than the numbers used in the present study. For example, in Quebec, where hydro plants generate most of the electricity, the average heat rate and CO_2 emission factor for their generation facilities would be close to zero.

4 RESULTS

4. RESULTS

4.1 Interpretation of the Results

The data presented in this section are energy-intensity and CO_2 emission-intensity indicators. These indicators were designed and are intended for the sole use of evaluating the efficiency with which energy is consumed by the process or plant being evaluated. The indicators illustrate how changes in technology and practice within the boundary of the particular process under review could improve energy efficiency and reduce CO_2 emission intensity.

The energy-intensity and CO_2 emission-intensity indicators, although expressed in identical units, are *not* specific energy consumptions and specific CO_2 emissions, neither for the processes and plants evaluated nor for the industry as a whole. They can differ significantly from the actual specific energy-consumption numbers and specific CO_2 emission numbers for the participating steel plants. (The reasons for the differences are given in Section 3.1, "Energy-Intensity Indicators.") Therefore, they must not be used for energy consumption and emission reporting.

The energy-intensity indicators for fuel consumption are based on the lower (or net) heating values for the fuels consumed. They will differ from indicators derived from Canadian fuel consumption energy-reporting data, which are based on the higher (or gross) heating value for the fuels consumed.

The energy-intensity and CO_2 emission-intensity indicators provide some insight into the potential to improve energy efficiency and reduce CO_2 emission intensity by implementing available technology. However, quantifying the potential to improve energy efficiency and reduce CO_2 emission intensity is not an objective of this study, and the methods used for energy benchmarking are not intended for that purpose.

The results identify opportunities for implementing technologies that are technically possible. However, the implementation of a particular technology may not necessarily be economically attractive. That decision can be made only by the plants that are considering the technology.

4.2 Presentation of the Results

The results for each process area are arranged and numbered so that the energy-intensity indicator, technology penetration and CO_2 emission-intensity indicator for a particular participating plant are linked.

Each bar on the Energy-Intensity Indicator charts for a particular process area (or reheating furnace type or plant) represents the performance of that process at a participating plant. The first bar is always the EcoTech Plant. The adjacent bars are arranged and numbered in order of energy-intensity-indicator ranking for the process. For example, Plant 1 is the plant with the best energy-intensity indicator; Plant 2 is the second best, etc. The plant numbers are provided to link the energy-intensity indicator, technology penetration and CO_2 emission-intensity indicator of a plant.

The arrangement and numbering of the columns in the Technology Penetration tables are the same as those on the corresponding Energy-Intensity Indicator charts. If a plant is Plant 2 on the Energy-Intensity Indicator chart for a particular process, it is also Plant 2 on the Technology Penetration table for that process. Hence, the energy-intensity indicator bar and the technology penetration for a particular plant will be in line on the charts.

The arrangement and numbering of the plants on the CO_2 Emission-Intensity Indicator charts are also the same on the corresponding Energy-Intensity Indicator charts. If a particular process at a plant is shown as Plant 2 on the Energy-Intensity Indicator chart, it is also shown as Plant 2 on the CO_2 Emission-Intensity Indicator chart.

There is no specific relation between the numbering of the plants on the charts and tables, and the identity of the plants. Also, there is no correlation between the numbering of the plants on the charts and tables from one process area to another.

4.3 Process Areas

4.3.1 Cokemaking – Figures 4-1 and 4-2

Energy-Intensity Indicators

- Canadian cokemaking operations are significantly less efficient than those of the EcoTech Plant. Based on the energy-intensity indicators, they require 60 to 110 percent more energy than does the EcoTech Plant. Since the addition of the EcoTech Technologies to the operating plants would not bring their efficiency into line with that of the EcoTech Plant, other factors must be adversely affecting the energy efficiency.
- All plants use more fuel (15 to 60 percent) for coke oven underfiring than does the EcoTech Plant.
- All plants use much more steam (four to seven times more) than does the EcoTech Plant.
- All plants use much more electricity (60 to 115 percent) than does the EcoTech Plant.

Technology Penetration

- High-pressure ammonia liquor spray aspiration could be employed to replace steam aspiration at the three plants that do not have this technology.
- Variable speed drives could be installed at all plants to reduce electricity and steam consumption. The opportunity would be less for Plants 1 and 4, which reported that they already use variable speed steam drives.

- Enhanced combustion control should be investigated as a means of reducing fuel consumption at all plants. Although Plant 3 uses this technology, fuel consumption has room for improvement.
- The remaining technologies offer potential for further energy savings but may not be economically feasible. The applicability of these technologies should be investigated after the other improvements are in place.

CO_2 Emission-Intensity Indicators

- The high direct CO_2 emission-intensity indicator for Plant 2 results from using blast furnace gas to underfire the coke ovens.

Other Considerations

- Enhanced combustion control improves combustion efficiency by reducing the amount of excess combustion air. However, there may be reasons why combustion efficiency cannot be improved. The age and condition of coke ovens affects the fuel required for underfiring. As ovens deteriorate, excess combustion air levels, which rob heat from the ovens, must be increased to prevent smoking, which is environmentally unacceptable. Under such conditions, better combustion control cannot be employed. Further investigation is required to establish if the apparent potential for the application of enhanced combustion control is feasible.
- The partial penetration of technology for high-pressure ammonia liquor spray aspiration, by itself, does not account for the high steam consumption. There have to be other reasons to explain the difference in steam consumption. Information about the technologies used at the by-product plant and the products produced was not given for the EcoTech Plant and was not collected for the plants participating in the present study. It may well be that the by-product plants operating in Canada are of broader scope, or differ considerably in function and equipment, than those used to define the EcoTech Plant. If so, the EcoTech Plant may not be a fair comparison for the Canadian plants. However, considering the quantity of steam consumed at the cokemaking plants, there is likely an opportunity to increase energy efficiency through improved steam system practices (insulation of lines and equipment, steam trap maintenance, steam leak repair, condensate recovery, etc.). Improved efficiency of equipment (steam turbines, heat exchangers, distillation and mass transfer equipment) may also be possible.
- The large potential indicated for reduction in electricity consumption also cannot be explained by technology penetration. Such high intensity relative to the EcoTech benchmark indicates that the easy and lucrative electrical-energy-reduction practices are not in place. Considering that electricity is an external energy source and cost, an audit of electricity use is recommended.

Before embarking on measures to reduce coke oven fuel and steam consumption, see Section 4.5.2, “Energy Management at Integrated Steel Plants.”

4.3.2 Ironmaking – Figures 4-3 to 4-7

For the purpose of better understanding the differences in performance and identifying potential energy-intensity-improvement opportunities, the ironmaking process area is subdivided into four areas: blowing, stoves, blast furnace and pulverized coal preparation. These four areas work as a system, and it is necessary to adjust operating practice so that the combined results are optimized. Therefore, it is sometimes necessary to operate one of the areas in a way that is less efficient in order to achieve a greater gain in efficiency for the overall ironmaking process.

4.3.2.1 Blowing – Figure 4-3

Energy-Intensity Indicators

- Blowing efficiency could be improved at Plants 2, 3 and 4.

Technology Penetration

- Axial-flow blowers are in place at Plant 1. Considering that axial-flow blower efficiency can reach 90 percent compared with 70 percent maximum efficiency for radial-flow blowers, this technology can reduce blowing energy consumption by 20 percent. Implementing axial-flow blowers at Plants 2, 3 and 4 would bring blowing energy consumption in line with that of Plant 1.
- Three plants use oxygen enrichment rates of 50 normal cubic metres per tonne of hot metal production (Nm^3/thm) or more. That practice exceeds both the EcoTech Plant and AllTech Plant practices. The oxygen enrichment rate at the other plant is less than the 35 Nm^3/thm rate for the EcoTech Plant. On average, this technology is well established in Canada.

Other Considerations

The integrated plants studied are equipped with blowers driven by steam turbines. The EcoTech Plant is based on using half the blowers with electrical drives and half with steam drives. Both the steam and electricity supply are outside of the blowing process area. Therefore, the efficiency at which they are generated should not be reflected in the blowing energy indicator. For an all-steam-drive situation, the EcoTech indicator would increase from 740 MJ/thm to 804 MJ/thm. Plant 1 steam consumption of 823 MJ/thm compares favourably with that value.

Most Canadian plants operate with one blower. Hence, it would not be possible to operate with half electrical drives and half steam drives, as suggested by the EcoTech Plant.

Blowers are extremely expensive equipment, and increased energy efficiency alone would not justify replacing them.

Aside from equipment technology (axial flow versus centrifugal blowers), the energy required for blowing is proportional to the mass of air delivered. Since the purpose of blowing is to deliver oxygen to the blast furnace for combustion of the fuel, oxygen enrichment reduces the volume of air needed, with each cubic metre of oxygen enrichment reducing the air requirement by five cubic metres.

The energy requirement for blowing also increases in proportion to the pressure at which the air is delivered. Higher pressure improves the performance of the blast furnace and enables a reduction in the amount of coke used in the furnace. These factors offset the higher blower energy consumption.

Blowing energy also depends on the steam available to power the turbines that drive the blowers. Steam at higher pressure and temperature can be more efficiently converted into power by the turbines. However, the effect of steam pressure was not reflected in the results.

Before embarking on measures to reduce blowing steam consumption, see Section 4.5.2, "Energy Management at Integrated Steel Plants."

4.3.2.2 Stoves – Figure 4-4

Energy-Intensity Indicators

- All plants use more fuel (14 to 42 percent) for stove heating than does the EcoTech Plant.
- Plants 2 and 3 use much more electricity (four to seven times as much) than does the EcoTech Plant.
- Plant 4 was operating with abnormally high excess combustion air due to damaged stove burners. That mode of operation decreases combustion efficiency and helps explain the high energy intensity.

Technology Penetration

- Waste-heat-recovery technology could be implemented at three plants to reduce fuel consumption.
- Staggered/parallel stove operating practice is not used and is not feasible for Canadian plants. The staggered/parallel stove operating practice employed by the EcoTech Plant requires four stoves, whereas Canadian blast furnaces operate with three stoves. (Stoves are extremely expensive, and it is more economical to build three large stoves than four smaller stoves.) Staggered/parallel stove operating practice is economically attractive only for plants that already have four stoves.
- Oxygen enrichment of the blast is used at all plants (see Figure 4-3 for details). There is little potential to increase the use of this technology.
- None of the plants has stove combustion controls that achieve the EcoTech Plant practice of limiting the excess combustion air to 5 percent. Some operations require higher excess air levels during the later part of the heating cycle to cool the flame, so that the flame temperature will not exceed the melting temperature of the stove dome refractory. Such operations would need to first implement individual stove fuel-blending technology to enable only cool-burning blast furnace gas for the later part of the heating cycle.

- The stove efficiency at all plants is less than the 85 percent EcoTech Plant level. Stove efficiency is a metric that reflects the overall performance of the stoves and is not related to a specific technology or practice. It is more meaningful than the energy-intensity indicator. Higher stove energy per tonne of hot metal production may be more an indicator of the amount of energy supplied to the blast furnace in the hot blast than an indicator of energy efficiency of the stoves. The fuel required at the blast furnace can be reduced by supplying more energy to the blast furnace in the hot blast from the stoves.

Other Considerations

Waste-heat-recovery technology is employed by the EcoTech Plant to reduce stove fuel consumption. (Stove efficiency is increased by using heat in the waste gas to preheat combustion air.) Waste-heat-recovery technology is in place only at Plant 2. However, it is a different technology than that referenced in the EcoTech Plant. The heat is recovered and used externally for another process that, in turn, reaps the benefit.

The large potential indicated for reduction in electricity consumption at Plants 2 and 3 cannot be explained by technology penetration. Such poor efficiency relative to the benchmark is an indication that the easy and lucrative electrical-energy-reduction practices are not in place. Considering that electricity is an external energy source and cost, an audit of electricity use is recommended. The first place to look would be the efficiency and operating practice of the stove combustion air fans, which are the large electricity consumers.

Before embarking on measures to reduce stove fuel consumption, see Section 4.5.2, "Energy Management at Integrated Steel Plants."

4.3.2.3 Blast Furnace – Figure 4-5

Energy-Intensity Indicators

- Furnace 1 is operating as efficiently as the blast furnace of the EcoTech Plant.
- Furnaces 2 and 4 have achieved the EcoTech Plant coke rate.
- Furnace 4 uses considerably more fuel than the others do. It may have an opportunity to reduce furnace fuel consumption.

Technology Penetration

Blast furnace injectants (fuels injected to reduce the amount of coke required) are used extensively at all plants. The use of blast furnace fuel injection is not intended to reduce the energy intensity of the blast furnace process. In fact, this technology may cause a blast furnace to operate at higher energy intensity. The purpose of blast furnace fuel-injection technology is to reduce the dependency on coke, which decreases the overall plant energy consumption per tonne of product, because cokemaking is energy intensive.

- An additional bar has been added to the chart to show the combined performance of all four blast furnaces. As a whole, the rate of blast furnace fuel injection has exceeded the EcoTech level of 3870 MJ/thm, and the coke rate is approaching that of the EcoTech Plant.

- Plants 2 and 4 have reduced specific coke consumption to the EcoTech Plant level. However, both furnaces have fuel-injection rates and, consequently, total fuel rates, which are considerably higher than the rates of the EcoTech Plant.
- Plant 3 has potential to increase blast furnace fuel injection by 50 percent. That would achieve the EcoTech Plant injection rate and bring with it a 15 percent reduction in specific coke consumption.

The other plants have some potential to increase the use of injectants and to reduce the coke rate.

Blast furnace top gas recovery turbine technology has not been implemented in Canada. The potential amount of energy to be recovered using this technology increases with the pressure at the top of the blast furnace. Canadian blast furnaces are designed to operate at a relatively low furnace-top pressure. Therefore the potential for recovering energy would be less than that for the EcoTech Plant, and the technology may not be economically attractive. Also, the price of electricity in Ontario, the province in which all Canadian blast furnaces are operated, has been historically low relative to the price in other countries. However, as the price escalates, a second look would be warranted.

Other Considerations

Using the EcoTech Plant coal-injection rate may not be appropriate for Canada's blast furnaces. Natural gas is readily available and relatively inexpensive in Ontario. Based on the performance of Furnaces 1 and 2, it appears to be the most effective and most favoured injectant. Coal and oil are favoured in other jurisdictions because of lower cost. Fuels that contain sulphur (coal, oil) can be used in the blast furnace because the sulphur is removed in the slag.

4.3.2.4 Pulverized Coal Injection (PCI) Preparation – No Figure

Considerations

- The EcoTech energy-intensity indicator includes the energy for preparation of pulverized coal for injection. Since only one plant has a PCI preparation facility, data cannot be shown and no comparison of Canadian operations can be made.
- Including PCI preparation could be considered unfair because the preparation energy for other injectants (cleaning and pressurization of natural gas, refining of oil) is not included. However, PCI preparation energy is a small component of the total ironmaking energy and is included only to be consistent with the reference EcoTech Plant.

4.3.2.5 Ironmaking – Figures 4-6 and 4-7

Energy-Intensity Indicators

- The overall energy efficiency of ironmaking is dominated by the Blast Furnace performance.
- The cumulative effect of the energy consumption in the Blowing, Stoves and PCI Preparation areas is apparent, and inefficiencies in those areas contribute to the differences between the performance of Plants 1–4 and that of the EcoTech Plant.

Technology Penetration

- Technology penetration is evaluated and discussed in Sections 4.3.2.1, 4.3.2.2 and 4.3.2.3 (above).

4.3.3 Basic Oxygen Furnace (BOF) Steelmaking – Figures 4-8 and 4-9

Energy-Intensity Indicators

- The energy credit for plants equipped with suppressed combustion hoods to collect BOF gas as a fuel is more than twice that for plants equipped with full combustion hoods that burn the gas as it evolves from the vessel to produce steam.
- All plants use twice as much electricity as does the EcoTech Plant. The carbon and oxygen energy inputs at all plants are in line with the EcoTech Plant practice. However, the use of other energy inputs (natural gas, steam, electricity) is greater than that for the EcoTech Plant.

Technology Penetration

- Two plants are equipped with BOF gas recovery systems. These systems use wet gas scrubbers to clean and cool the gas. The EcoTech Plant is equipped with a dry gas cleaning system, and the gas is cooled by steam generators that recover the heat. Gas recovery technology employing dry gas cleaning and steam recovery is required to achieve the energy efficiency of the EcoTech Plant.
- All plants practice ladle management and use lids to retain heat in the ladles. Ladle heaters are not equipped with waste heat recovery (recuperators).

CO_2 Emission-Intensity Indicators

- CO_2 emission intensity for plants equipped with gas recovery systems is low because the gas is delivered to other process areas, which include gas flares.

Other Considerations

- Energy recovery offers the largest opportunity to improve BOF efficiency. Gas collection technology is economically attractive when building new facilities, but it is most likely not economically feasible to abandon the steam recovery systems already in use and replace them with gas recovery systems.
- Canadian plants that recover waste heat as steam are equipped with half-boiler technology, in which the gas is partially cooled in a radiant boiler hood. Full-boiler steam recovery technology includes the radiant boiler hood followed by a convection boiler tube bank.[13] The amount of energy recovered as steam by the full-boiler technology approaches that which can be recovered by the gas collection system. Plants equipped with steam recovery systems might be better advised to consider upgrading to the full-boiler technology, rather than converting to a gas collection system.
- The relative advantage of gas recovery systems depends on how the recovered gas is used. Both plants that recover BOF gas have not invested in the gasholder and distribution system required to deliver the gas to potential users. Hence, the gas is flared, resulting in

[13] See Chapter 6, reference 3, page 119.

an energy-intensity disadvantage compared with the plants equipped with steam recovery systems.

- The excessive use of electricity may reflect high utilization of the ladle metallurgy facility (LMF) at the plants. The LMF is an electric arc furnace that adjusts the temperature and chemistry of the steel prior to casting. The amount of steel treated in the LMF depends on the grades of steel produced, with plants that produce high-grade steel having greater LMF utilization and electricity consumption.
- The LMF can also be used to increase steel production. More scrap is added to the BOF, which results in a drop in liquid steel temperature, but the temperature is restored by electrical-energy input at the LMF. This practice should be competitive with, and as energy efficient as, electric arc furnace steelmaking.

4.3.4 Electric Arc Furnace (EAF) Steelmaking and Continuous Casting – Figures 4-10 and 4-11

Note: To be consistent with the energy-intensity indicators provided for the EcoTech Plant, EAF Steelmaking and Continuous Casting are shown as separate processes in Figure 3.1. However, it was not possible to separate them for energy benchmarking because most EAF plants meter and account for EAF Steelmaking and Casting energy flows as single entities. Also, while four integrated plants took part in the study, eight of the nine EAF plants took part.

Energy-Intensity Indicators

- All plants consume 35 to 700 percent more natural gas than does the EcoTech Plant.
- All plants consume 2 to 40 percent more electricity than does the EcoTech Plant.

Technology Penetration

- All nine plants incorporate at least five of the eight EcoTech Technologies. Five plants have six and one plant has seven of the EcoTech Technologies in place. Average penetration of EcoTech Technologies is 76 percent (six of eight plants), an indication that there is not a lot of opportunity left.

CO_2 Emission-Intensity Indicators

- Oxy-Fuel Burners and Supplementary Fuel are two EcoTech Technologies that reduce the energy intensity of the EAF process. Use of fuel, of course, increases direct emissions. However, the consumption of electricity is reduced, and the resulting reduction in indirect emissions can result in a net emission reduction if fossil fuel power generation is on the margin. (A power generation facility is deemed to be on the margin if it is dispatched to respond to the incremental increases and decreases in demand.)

Other Considerations

- No correlation can be seen between technology penetration and the energy-intensity performance of the plants. Plant utilization also failed to explain the difference in plant efficiency. It appears that other operating and general energy-management practices must be influencing the energy efficiency of the EAF Steelmaking and Casting process area.

4.3.5 Continuous Casting – Figures 4-12 and 4-13

Note: The results in this section are for the integrated plants where casting operation energy flows are metered and accounted for separately.

Energy-Intensity Indicators

- All plants consume 80 to 450 percent more energy than does the EcoTech Plant.

Technology Penetration

- There are no energy-saving technologies specific to the Continuous Casting process.

Other Considerations

- General energy-saving practices and technologies should be investigated as a means of bringing caster energy efficiency into line with that of the EcoTech Plant benchmark.

4.3.6 Hot Strip and Plate Mills – Figures 4-14 and 4-15

Energy-Intensity Indicators

- The Hot Strip Mills consume 20 to 270 percent more fuel than does the EcoTech Plant Hot Strip Mill.
- The Plate Mills consume 220 to 570 percent more energy than does the EcoTech Plant Plate Mill.
- Except for Plant 7, the energy-intensity ranking of each plant is determined by fuel consumption.

Technology Penetration

- Four of the six Hot Strip Mills are equipped with Coilbox technology; only one mill is equipped with Thermal Cover technology. The Coilbox and Thermal Cover technologies reduce heat loss from the steel during rolling. By reducing the heat loss, less heat needs to be supplied to the steel by the reheating furnace, which reduces furnace fuel consumption. Also, the steel remains at a higher temperature throughout the rolling process, which reduces the electrical power required to form it during rolling.
- Schedule-Free Rolling, Transfer Bar Edge Heating and High Edging Capability are technologies that facilitate hot slab charging.[14] The poor penetration of hot slab charging, which is shown in Section 4.6.1, "Slab Reheating Furnaces," may be attributed to the lack of implementation of these rolling mill technologies.
- One mill is equipped with Alternating Current Roughing Mill Motor. Alternating current motors are more efficient than the traditional direct current drives.
- The energy-intensity ranking of the mills is, almost without exception, a reflection of the energy-intensity ranking of their slab reheat furnaces. The penetration of energy-saving furnace technology for the furnaces operated at these mills is shown in Section 4.6, "Reheating Furnaces."

[14] See Chapter 6, reference 1, section 3.6.4.6, page 104.

Other Considerations

- There is major potential for the Hot Strip Mills and Plate Mills to increase the energy efficiency in their slab reheating operation. That potential, and the penetration of applicable furnace energy-saving technologies, is also discussed in Section 4.6, "Reheating Furnaces."

4.3.7 Section Mills – Figures 4-16 and 4-17

Energy-Intensity Indicators

- Section Mills are divided into three categories based primarily on the size (section area or weight per metre) of the product. The EcoTech Plant energy efficiency is different for each category. The Medium Section (Bar) Mill requires the least energy. The Light Section (Rod) Mill requires more energy in the rolling process because the steel has to be worked down to the smaller section. Heavy Section (Bloom and Structural) Mills require more energy because it is more difficult to heat the large blooms that feed these mills and to roll the complex structural shapes.
- The Section Mills consume from 10 percent less to 90 percent more fuel than do the mills of the EcoTech Plant.
- Fuel consumption at Plants 1, 2, 4, 5, 6 and 7 is in line with that of the EcoTech Plant, indicating efficient furnace operation.
- Electricity consumption at Plants 4, 5, 7, 11 and 12 is less than that of the EcoTech Plant.

Technology Penetration

- The penetration of energy-saving furnace technologies for Section Mills is shown in Section 4.6.2, "Billet and Bloom Reheating Furnaces."
- There are no EcoTech Technologies for Section Mill rolling equipment.

4.4 Plants

This section provides energy-intensity and CO_2 emission-intensity indicators for plants.

Penetration of technology and practices was evaluated at the process level and, therefore, is not repeated at the plant level.

In addition to reflecting the energy intensity and CO_2 emission-intensity of the processes that make up the plants, the plant results also indicate the effect of product input factors. The energy used to produce intermediate product, which is lost to oxidation or scrapped/recycled because it is unsuitable for further processing or sale, is distributed over the final product.

Interpretation and comments on the plant results are limited to new insight that was not apparent in the results for the processes.

4.4.1 EAF Plants

The plant results show the energy-intensity indicator and the CO_2 emission-intensity indicator for each hot rolled product made by the EAF plants. The EAF plants were constructed by coupling the EAF Steelmaking and Casting process at each EAF plant to each hot rolling process in operation at that particular plant.

4.4.1.1 EAF Rod Plant – EAF, Caster and Rod Mill – Figures 4-18 and 4-19

This plant produces rod products from steel made by the EAF process. The plant is constructed by linking the EAF Steelmaking and Continuous Casting processes (Figure 4-10) and Rod Mills (Figure 4-16). Billet and Bloom Reheating Furnaces (Figure 4-50) also provides some insight into the relative performance of the EAF Rod Plants.

The energy intensity of the EAF Rod Plants is 12 to 21 percent more than that of the EcoTech Plant. Plant 2 consumes 33 percent more electrical energy than does the EcoTech Plant.

4.4.1.2 EAF Bar Plant – EAF, Caster and Bar Mill – Figures 4-20 and 4-21

This plant produces bar products from steel made by the EAF process. The plant is constructed by linking the EAF Steelmaking and Continuous Casting processes (Figure 4-10) and Bar Mills (Figure 4-16). Billet and Bloom Reheating Furnaces (Figure 4-50) also provides some insight to the relative performance of the EAF Bar Plants.

The energy intensity of the EAF Bar Plants is 14 to 60 percent more than that of the EcoTech Plant.

4.4.1.3 EAF Hot Strip Plant – EAF, Caster and Hot Strip Mill – Figures 4-22 and 4-23

This plant produces hot strip coils from steel made by the EAF process. The plant is constructed by linking the EAF Steelmaking and Continuous Casting processes (Figure 4-10) and Hot Strip Mill (Figure 4-14). Slab Reheating Furnaces (Figure 4-49) also provides some insight to the relative performance of the EAF Hot Strip Plants.

The energy intensity of the EAF Hot Strip Plants is 14 to 40 percent more than that of the EcoTech Plant.

4.4.2 Integrated Plants

The plant results show the energy-intensity and CO_2 emission-intensity indicators for each intermediate product (liquid iron, liquid steel and cast steel) and for final hot strip and plate products. Additional plants are provided for the production of final hot strip and plate products with the inclusion of plant gas flares and plant utility processes (gas flares, water supply and treatment, and power plant).

4.4.2.1 Integrated Iron Plant – Cokemaking and Ironmaking – Figures 4-24 and 4-25

The first intermediate product of the integrated plant is liquid iron (often referred to as hot metal). The Integrated Iron Plant is configured by linking the Cokemaking process (Figure 4-1) to the Ironmaking process (Figures 4-3 to 4-6).

4.4.2.2 Integrated Steel Plant – Coke Ovens, Blast Furnace and BOF – Figures 4-26 and 4-27

The second intermediate product of the integrated plant is liquid steel. The Integrated Steel Plant is configured by linking the BOF process (Figure 4-8) and the BOF Gas Flares to the Integrated Iron Plant.

4.4.2.3 Integrated Semifinished Steel Plant – Coke Ovens, Blast Furnace, BOF and Caster – Figures 4-28 and 4-29

The final intermediate product of the integrated plant is semifinished (cast) steel. The Integrated Semifinished Steel Plant is configured by linking the Continuous Casting process (Figure 4-12) to the Integrated Steel Plant.

4.4.2.4 Integrated Hot Strip Plant – Integrated Semifinished Steel Plant and Hot Strip Mill – Figures 4-30 and 4-31

The Integrated Hot Strip Plant is configured by linking the Hot Strip Mill process (Figure 4-14) to the Integrated Semifinished Steel Plant.

For completeness of the present analysis of hot strip steel production, it is necessary to introduce the cast-and-roll hot strip mill process at this stage. One integrated plant in Canada uses this process and the conventional hot strip mill process so, on an analytical basis, the number of plants under study increases from four to five. In this scenario, the cast-and-roll process is linked to the Integrated Steel Plant.

4.4.2.5 Integrated Hot Strip Plant and Gas Flares – Integrated Semifinished Steel Plant, Hot Strip Mill and Gas Flares – Figures 4-32 and 4-33

The Integrated Hot Strip Plant and Gas Flares is configured by linking the Hot Strip Mill process (Figure 4-14) and the Gas Flares (Figure 4-46) to the Integrated Semifinished Steel Plant.

4.4.2.6 Integrated Hot Strip Plant and Utilities – Integrated Semifinished Steel Plant, Hot Strip Mill and Utilities – Figures 4-34 and 4-35

The Integrated Hot Strip Plant and Utilities is configured by linking the Hot Strip Mill process (Figure 4-14) and the Utilities to the Integrated Semifinished Steel Plant.

4.4.2.7 Integrated Plate Plant – Integrated Semifinished Steel Plant and Plate Mill – Figures 4-36 and 4-37

The Integrated Plate Plant is configured by linking the Plate Mill process (Figure 4-14) to the Integrated Semifinished Steel Plant.

4.4.2.8 Integrated Plate Plant and Gas Flares – Integrated Semifinished Steel Plant, Plate Mill and Gas Flares – Figures 4-38 and 4-39

The Integrated Plate Plant and Gas Flares is configured by linking the Plate Mill process (Figure 4-14) and the Gas Flares (Figure 4-46) to the Integrated Semifinished Steel Plant.

4.4.2.9 Integrated Plate Plant and Utilities – Integrated Semifinished Steel Plant, Plate Mill and Utilities – Figures 4-40 and 4-41

The Integrated Plate Plant and Utilities is configured by linking the Plate Mill process (Figure 4-14) and the Utilities to the Integrated Semifinished Steel Plant.

4.4.3 EAF Plant with Direct Reduced Iron

4.4.3.1 Direct Reduced Iron and Integrated Hot Strip Plants – DRI Plant, EAF, Caster, Hot Strip Mill, and Integrated Hot Strip Plant and Utilities – Figures 4-42 and 4-43

The MIDREX process, which produces solid direct reduced iron (DRI), is unique to one Canadian plant and, therefore, was not included in the Process Areas section. The iron made in the MIDREX® Shaft Furnace is usually melted and converted to steel by the EAF process and, therefore, is considered a substitute for scrap. The Direct Reduced Iron, Electric Arc Furnace, Hot Strip Plant (DRI-EAF Hot Strip Plant) is considered to be a variation of the EAF Hot Strip Plant, which was previously defined in Section 4.4.1.3. The only difference is that a portion of the scrap charged to the EAF is replaced with DRI.

The DRI-EAF Hot Strip Plant is included in this study to provide some insight as to how a plant based on an alternate iron-producing technology compares with an integrated plant. However, the process equipment and the material inputs and outputs for the DRI process differ significantly from those of the blast furnace process. Therefore, any comparison between the two is not consistent with normal energy benchmarking practice and is not intended to indicate how the energy intensity and CO_2 intensity of either type of plant might be reduced.

The EcoTech DRI-EAF Hot Strip Plant includes EcoTech energy-intensity data for the MIDREX process.[15]

The energy intensity of the EAF process increases somewhat as increasing amounts of DRI are substituted for scrap. The EcoTech EAF energy-intensity indicator for a 100 percent scrap charge practice is 5079 MJ per tonne of liquid steel. The EcoTech EAF energy-intensity indicator for the typical practice of charging 60 percent DRI and 40 percent scrap is 5805 MJ per tonne of liquid steel.[16] (The EcoTech DRI-EAF Hot Strip Plant, in fact, includes the energy-intensity indicator for the 60 percent DRI and 40 percent scrap practice.) Accordingly, the EAF process at DRI Plant 1 on Figures 4-42 and 4-43, which operates close to this DRI/scrap ratio, can be readily compared with that of the EcoTech DRI Plant.

Energy-Intensity Indicators

- The energy intensity of the EcoTech DRI-EAF Hot Strip Plant is close to that of the EcoTech Integrated Steel Hot Strip Coil Plant.
- The energy intensity of DRI-EAF Hot Strip Plant 1 is at the lower end of the range of energy intensity for the integrated plants.
- The DRI-EAF Hot Strip Plant uses significantly less fuel and more electricity than do the integrated plants.

[15] See Chapter 6, reference 1, page 179.
[16] See Chapter 6, reference 1, page 91.

- Most of the electricity used in the DRI-EAF Hot Strip Plant is consumed by the EAF process. (Typically, melting and refining in an arc furnace accounts for close to 90 percent of the total electricity used in an EAF-based steel plant.)

CO_2 Emission-Intensity Indicators

- The DRI Plant direct CO_2 emission intensity is much less than that for the integrated plants. This reflects the lower fuel use at the DRI Plant, with natural gas being the major fuel input, whereas coal (coke and coke oven gas) is the major fuel input to the integrated plants.
- The DRI Plant indirect CO_2 emission intensity is much greater than that for the integrated plants. This reflects the higher use of electricity in the EAF process and the assumption, in the current study, that all electricity is produced at coal-fired power plants.
- The DRI Plant total CO_2 emission intensity is less than that for the integrated plants. This reflects the use of natural gas, which is less carbon intensive than the coal used at the integrated plants, and the higher level of scrap steel input to the DRI Plant.

Other Considerations

- The amount of scrap steel input for the DRI-EAF Plant is significantly different than that used for the integrated plant. Any proportion of DRI and scrap can be charged into the EAF steelmaking process, with a typical practice being a 60 percent DRI and 40 percent scrap charge. For integrated plants, the scrap charged into the BOF steelmaking process must be melted by the energy in the liquid iron derived from the blast furnace process. This limits the amount of scrap that can be charged at the integrated plants, so that the typical practice is 10 to 20 percent. The energy intensity for producing steel by melting scrap in the EAF is less than half that for producing steel from iron ore (see Section 2.2, “Energy Use,” for details) because no energy is required for converting iron oxide (ore) to iron. Therefore, in the comparison of energy intensity for DRI-EAF Plants and integrated plants, the relative efficiency of the iron ore reduction process is masked by the favourable effect of the higher level of scrap input to the steelmaking process at the DRI-EAF Plant.
- The MIDREX DRI process, which is natural gas based, offers an opportunity to produce iron and quality steel from energy sources other than coal and, hence, significantly reduce the CO_2 emission intensity of steel production. The DRI process is followed by the EAF process, which is electricity intensive. However, if an EAF plant is in a jurisdiction where electricity is produced by hydraulic or nuclear power plants, and not by fossil-fuel-fired power plants, it would, in fact, cause no indirect CO_2 emission.[17]

[17] As previously explained in Section 3, throughout the present study, all electrical-energy-intensity values have been converted to fossil fuel input using a factor of 9200 MJ/MWh, which assumes 100 percent fossil fuel generation. To be consistent, the CO_2 emission factor used to calculate external CO_2 emission-intensity indicators must be 856 kg/MWh. These factors were deemed to be representative of fossil fuel power generation in Europe by the International Iron and Steel Institute and the European Steel Energy Committee (see Chapter 6, references 1 and 2). By using these factors, the results of the present study are comparable with IISI and ESEC benchmarking practice.

- The DRI-EAF Hot Strip Plant included in the present study is in Quebec, where almost all electricity is generated at hydraulic plants. The integrated plants are all in Ontario, where a good portion of the electricity is generated by hydraulic or nuclear facilities. For hydraulic or nuclear power plants, the energy-intensity factor for generating electricity is 3600 MJ/MWh, and the CO_2 emission-intensity factor is zero. Therefore, in reality, the *indirect* CO_2 emission intensities for the plants are much less than those shown on Figure 4-43. The real issue is *direct* CO_2 emission intensity.
- The direct CO_2 emission intensity for the EcoTech DRI-EAF Hot Strip Plant is only 479 kg CO_2 per tonne, which is considerably less than the 1547 kg CO_2 per tonne of direct CO_2 emission intensity for the EcoTech Integrated Hot Strip Plant.
- The same could be said of CO_2 emission intensity for steel produced only from scrap by the EAF process. The direct CO_2 emission intensity for the EcoTech EAF Hot Strip Plant (Section 4.4.1.3, "EAF Hot Strip Plant," and Figure 4-23) is only 130 kg CO_2 per tonne. However, the quality of steel produced from salvaged scrap is generally not satisfactory for some steel applications due to impurities contained in scrap steel. Therefore, not all steel produced from scrap can be substituted for steel made from virgin iron at the integrated mills. The substitution of DRI for scrap at the EAF Plant can result in steel of sufficient quality to compete with most grades of steel from the integrated plants.
- In conclusion, the Midrex DRI-EAF Hot Strip Plant, powered by electricity generated by hydraulic or nuclear power plants, can produce quality steel at a CO_2 emission intensity that is significantly less than that for integrated plants.
- The feasibility of future DRI plants depends on the availability and price of scrap steel, natural gas and electricity. DRI processes have been available on a commercial scale since the 1950s and, when introduced, were considered to be a real alternative to the blast furnace. However, the expected large growth in DRI installations never took place due to the economics of the process. DRI plants have been built only in places favoured by low-cost natural gas and the availability of iron ore or where there was a need for scrap replacement in the EAF process (due to the availability and cost considerations or product quality requirements).[18] The ready availability of iron ore and the desire for good product quality were the main reasons for the implementation of the Midrex DRI Plant in Canada.

4.5 Plant Energy Management

This section provides an evaluation of the energy management practices at the participating plants.

4.5.1 Energy Monitoring and Reporting – Figures 4-44 and 4-45

To evaluate the extent that energy consumption is tracked, plants were asked to estimate the percentage of the energy data that was monitored for this energy benchmarking report. Energy inputs that are continuously metered and either recorded, data logged or integrated were deemed to be monitored.

[18] See Chapter 6, reference 1, page 170.

The extent of energy data monitoring is shown on the histogram “Energy Monitoring” (Figure 4-44). The bin categories, which are in 10 percent increments on the x-axis, indicate the maximum percentage for the group, e.g. the bar above 70 shows that four plants reported their level of monitored energy data to be between 60 and 70 percent.

Four plants reported 100 percent energy data monitoring, six plants reported between 60 and 80 percent, and the remaining plants reported some monitoring. On average, 72 percent of the energy data at the plants is monitored.

Energy monitoring is not considered an EcoTech Technology because, in one form or another, it has been in place at steel plants for many years. Energy monitoring leads to improved energy efficiency by increasing awareness of energy consumption and cost and by identifying and quantifying energy-saving opportunities. In many cases, it produces immediate savings by driving conservation and identifying over-billing.

It is doubtful that the full benefit of implementing EcoTech Technologies could be realized without total plant energy monitoring.

Energy reporting can be considered an indication of the priority and importance placed on energy efficiency by a company. To evaluate the extent of energy reporting, plants were asked to state the frequency that energy data are presented to the plant manager.

The extent of energy reporting is indicated on the histogram “Energy Reporting” (Figure 4-45). The bin categories show the energy reporting period. All plants except one report energy consumption monthly or more frequently. Monthly reporting to the plant manager is probably adequate because day-to-day issues are addressed at a lower level. Monthly reporting enables the plant manager to be made aware of, and address, major problems and to pursue opportunities to improve efficiency.

4.5.2 Energy Management at Integrated Steel Plants

At integrated steel plants, much of the energy management activity is focused on the plant utilities, which are shown as blue boxes on Figure 2-4. Efficient use of utilities minimizes the need to purchase external energy, usually natural gas and electricity, by optimizing the use of steel plant fuel gases (coke oven gas, blast furnace gas and BOF gas) and heat (steam and hot water) obtained from heat rejected from the production processes. The EcoTech strategy for employing the plant utilities to maximize efficiency includes the following:

- Equip reheating furnaces, coke ovens and blast furnace stoves to fire steel plant fuel gases, to minimize the purchase of other fuels.
- Burn the remaining steel plant fuel gases in a cogeneration power plant to produce electricity and steam for internal use and sale.
- Maximize the energy available for the generation of electricity by implementing energy conservation practices and technologies throughout the plant.

The EcoTech Plant illustrates that it is essential for an integrated plant to be equipped with an adequate and efficient cogeneration power plant, since there are practical and thermodynamic limits to the extent that purchased fuel can be displaced by improvements in energy efficiency. Many of the technologies and practices available for improving energy efficiency result in the generation of low-grade energy (low-temperature heat) that is not suitable for use in the high-temperature steelmaking processes. This low-grade energy must be converted to electricity to achieve improved energy efficiency and economic return.

4.5.2.1 Gas Flares – Figures 4-46 and 4-47

- All integrated plants flare considerably more steel plant fuel gas (4 to 40 times more) than does the EcoTech Plant.
- The flaring of blast furnace gas and BOF gas accounts for 85 percent of the gas burned off. In the EcoTech Plant, surplus blast furnace gas and BOF gas are used to generate electricity at the power plant. Therefore, the flaring of these gases at the integrated plants indicates a lack of capacity at the power plants to convert plant gases into electricity.

4.5.2.2 Power Plant – Figure 4-48

The EcoTech Power Plant is defined as a steam cogeneration plant with the following equipment and operating characteristics:

- Steam boilers generating superheated steam at a pressure of 180 bar and a temperature of 530°C and equipped with a steam reheater
- A steam turbogenerator set equipped to operate with one stage of steam reheat and six stages of steam extraction for regeneration or the supply of process steam
- An overall power generation efficiency of 32 percent when operated as a power plant (no steam extracted for process heating). The corresponding heat rate is 11.25 MJ/kWh.
- Sufficient boiler and turbogenerator capacity to use all available steel plant fuel gases and recovered heat

Figure 4-48 compares the power plant technology at the participating integrated plants with that of the EcoTech Plant:

- Boilers at the plants generate steam at pressures and temperatures that are much lower than those of the EcoTech Plant.
- The steam turbines at the plants are not equipped for steam reheat and operate with only one stage of regeneration.
- The technology in place at the power plants is capable of an overall power generation efficiency in the range of 22 to 24 percent when operated as a power plant (no steam extracted for process heating). The corresponding heat rates range from 15 to 16 MJ/kWh. A comparison of this range of heat rates with the heat rate of the EcoTech Plant shows that for a given energy input, the EcoTech Power Plant is capable of producing 38 percent more electrical energy.
- Plants 1 and 2 have some electrical generation capability, but it is a small percentage (3 and 18 percent, respectively) of the EcoTech Plant requirement. The other two plants reported no capability to generate electricity.

It appears that the power plants at all four integrated plants are inadequate for present energy management requirements and will become even more inadequate as EcoTech Technologies are implemented throughout the plants. The main inadequacies are lack of power generation capability and the inability to efficiently convert surplus energy into electrical energy.

4.5.2.3 Steam and Plant Fuel Gas Conservation

Referring to the figures for the integrated plants (Figures 4-24 to 4-41), it can be seen that utilities' consumption at all the integrated plants is extremely high compared with that of the EcoTech Plant. For example, the average utilities consumed per tonne of hot strip coil at the integrated plants was six times higher than the utilities requirement for the EcoTech Plant. Steam consumption accounts for most of the utilities consumption at the integrated plants. The excessive use of steam at the integrated plants is most likely another indication of inadequate power plants. Lacking the power plant equipment to generate electricity, there is little incentive to conserve steam. Reducing steam demand would reduce fuel demand at the power plant boilers that, in turn, would result in a proportional increase in the flaring of steel plant fuel gases. No energy, emission or cost savings would be realized.

Suitably sized cogeneration power plants, with the ability to efficiently convert steam and fuel gas into electrical energy, are required to provide the incentive for the plants to invest in such practices and technologies as the following:

1. Maintain and improve steam line insulation and steam traps.
2. Generate steam from the recovered heat from process waste gas streams.
3. Recover BOF gas and deliver it to the power plant boilers.
4. Improve boiler efficiency.
5. Improve blast furnace stove efficiency.
6. Improve the efficiency of coke ovens and reheating furnaces that burn coke oven gas.

4.6 Reheating Furnaces

4.6.1 Slab Reheating Furnaces – Figure 4-49

Note: Slab reheating furnaces are broken out of the Hot Strip Mill and Plate Mill process areas to better show the penetration of energy-saving furnace technologies and the contribution that the furnaces can make to reduce overall energy consumption of the mills.

Energy-Intensity Indicators

- All furnaces consume 15 to 250 percent more fuel than does the EcoTech Plant furnace.
- The EcoTech benchmark shown (1232 MJ/tonne) is for slab furnaces at Hot Strip Mills. The EcoTech benchmark for slab furnaces at Plate Mills assumes greater penetration of hot slab charging technology and, therefore, is less (1010 MJ/tonne).

Technology Penetration

- Hot slab charging practice is used by Furnaces 3, 4, 5 and 6. However, the average charging temperatures for Furnaces 3, 4 and 5 are below the hot charging criterion for the EcoTech Plant. Limited penetration of this technology contributes to the high fuel consumption reported.
- Furnaces 1, 2, 3 and 6 are equipped with recuperators to produce a combustion air preheat temperature that meets the EcoTech Plant criterion, whereas recuperation on Furnaces 4 and 5 leads to temperatures close to that level. Recuperation is an extremely effective energy-reduction technology, and as expected, the furnaces with reasonable recuperation are, without exception, the leaders in energy efficiency. Limited penetration of this technology at the other furnaces contributes to their indicated high fuel consumption.
- Most furnaces (15 of 17) are equipped with an unfired charge preheat zone. Only two have an unfired charge preheat zone longer than the 10.0-metre zone for the EcoTech Plant furnace. The average length of the unfired charge preheat zone for all furnaces is 7.5 metres, which indicates fair penetration of this technology. However, the technology appears to have much less effect on energy consumption than does recuperation.
- Four furnaces are equipped with evaporative skid cooling systems. Evaporative skid cooling uses the heat lost to the skid cooling system to produce steam, which is an energy output credit. The furnaces equipped with this technology are among the top five most energy efficient.
- One furnace is equipped with double-insulated (ceramic fibre and castable refractory) skid insulation. Double-insulated technology significantly reduces heat loss to the furnace skid cooling system. The furnace equipped with this technology is also among the top five most energy efficient.
- Twelve furnaces are equipped with Level II control systems, and nine of those are also equipped with Level III control. Level II control tracks each piece of steel as it travels through the furnace, calculates the amount of heat and time required to bring each piece up to rolling temperature, and adjusts the furnace temperature/firing rate to achieve the desired thermal state with the lowest possible fuel consumption. Level III control links the Level II control system to the mill scheduling computer, enabling the furnace controls to adjust in advance to operational changes, such as changes to the size and grade of the steel to be heated and production interruptions to reset the mill for product changes. Level II and Level III furnace control systems enable full advantage to be taken of the energy efficiency potential of the furnace. However, it is clear that control, by itself, cannot make up for the lack of energy-efficient features or poor furnace design and maintenance.
- Two furnaces are equipped with heat recovery steam boilers. One would expect a credit for the steam produced, rather than the large steam consumption reported for these furnaces.
- Six slab furnaces are equipped with most of the EcoTech Technologies, and they approach the EcoTech efficiency. The remaining 11 furnaces lack most, if not all, of the EcoTech Technologies and, accordingly, are extremely inefficient.

Other Considerations

- The EcoTech Plant furnace operates with 30 percent of the steel charged at 600°C, which reduces fuel consumption by 260 MJ/tonne, suggesting that hot charging is required to achieve the indicated furnace efficiency. Furnace 1, which is equipped with the other EcoTech furnace technologies, approaches the efficiency of the EcoTech Plant furnace.
- The EcoTech Plant furnace is equipped with recuperators that preheat the combustion air to 450°C. Preheating the combustion air increases the flame temperature, which is the main factor in the formation of nitrogen oxide (NO_X). Because NO_X is a pollutant, there are regulatory limits for it in jurisdictions where acid deposition and smog formation are a problem. NO_X emissions can be held below air-pollution-control-based limits by burner technology for combustion air preheats up to about 400°C. Above that temperature, the formation of NO_X increases rapidly, and costly end-of-pipe abatement equipment may be required. Hence, the feasibility of recuperation change and investing in more recuperation to raise combustion air temperature above 400°C may require trade-offs between energy efficiency, NO_X emissions and cost. If recuperation is limited to 400°C by NO_X air-pollution-control-based limits and economic considerations, then other forms of waste heat recovery are available to use the large amount of heat still contained in the waste gas. Steam recovery boilers are a consideration, but there must be a need for the steam to justify the boilers – and that is a plant energy management issue (see Section 4.5, "Plant Energy Management").
- The length of the unfired charge preheat zone of a furnace is difficult to change once the furnace is installed. It requires relocation of the furnace charge-end material handling system, which may not be possible due to mill layout and would definitely not be economically justifiable by the energy cost savings.
- Evaporative skid cooling technology is viable for the recovery of heat lost to the furnace skids. It also eliminates the energy used for water pumping and cooling tower fans in conventional water cooling skid systems. However, this technology is no substitute for good skid insulation. Making steam with evaporative skid cooling is much less efficient than making steam in a steam boiler. The energy-intensity indicators show that Furnaces 3 and 5 are making far too much steam and, hence, are not as efficient as Furnaces 1 and 2.
- Double-insulated furnace skids are effective in reducing heat loss to the skid cooling system. At plants that do not have steam systems, this technology would be preferable to evaporative skid cooling. However, skid insulation fails over time and needs to be repaired or replaced regularly to remain effective.
- Reducing heat loss to the furnace skid system is a requirement to achieving the efficiency of the EcoTech Plant furnace. A combination of evaporative skid cooling and double-insulated skids should be considered. Four furnaces are equipped with skid cooling heat recovery systems. However, these furnaces lose much more energy to skid cooling (especially Furnaces 3 and 5) than does the EcoTech Plant furnace, which can be seen in the amount of energy recovered. Excessive skid cooling heat loss is a reason that these furnaces are more energy intensive than the EcoTech Plant furnace. Furnace 4, which is equipped with double-insulated furnace skids, is as efficient as Furnaces 3 and 5, which are equipped with skid cooling heat recovery systems.

4.6.2 Billet and Bloom Reheating Furnaces – Figure 4-50

Note: Billet and Bloom reheating furnaces are broken out of the Rod Mill, Bar Mill and Heavy Section Mill process areas to better show the penetration of energy-saving furnace technologies and the contribution that the furnaces can make to the overall energy consumption of the mills.

Energy-Intensity Indicators

- Four furnaces have achieved energy efficiency greater than that of the EcoTech Plant furnace, and a fifth furnace is close. The other seven furnaces consume more (10 to 70 percent) energy than does the EcoTech Plant furnace.

Technology Penetration

- Furnaces 3, 4 and 8 are equipped with recuperators to produce a combustion air preheat temperature that meets the EcoTech Plant criterion. Recuperation on Furnaces 6 and 11 comes close to achieving the EcoTech Plant standard. Three furnaces are operating without recuperators.
- Most furnaces (8 of 12) are equipped with an unfired charge preheat zone. The average length of this zone for all furnaces is three metres, which indicates poor penetration of this technology.

Other Considerations

- The low-tech pusher furnace is known for high efficiency heating of small billets (under 150 mm). Since these billets are small enough to be heated from one side, there is no need for walking beams to space them in the furnace or for a skid system to support them for heating from the bottom. That makes the pusher furnace inexpensive to build and long unfired charge preheat zones economically attractive. Coupled with modest recuperation, these features result in an energy-efficient furnace, as can be seen by the efficiency of Furnaces 1 and 2.
- The comments made about recuperation in Section 4.6.1, “Slab Reheating Furnaces,” also apply here.
- Billet reheat furnaces require less extensive skid systems, and hence, evaporative skid cooling is often not economically feasible. Bloom furnaces that heat heavy blooms will have skid systems comparable to those in slab furnaces, and evaporative skid cooling systems should be economically attractive.
- Double-insulation skid technology can be economically applied regardless of the size of the skid system.
- The comments made about Level II and Level III furnace control in Section 4.6.1, “Slab Reheating Furnaces,” also apply here.

The following figures illustrate the penetration of furnace technologies that reduce furnace energy input (as opposed to technologies that recover heat rejected by the furnace). The effectiveness of these technologies in improving furnace energy efficiency is not necessarily cumulative. A complete thermal balance of a furnace is required to establish the combined effect of these technologies.

4.6.3 Combustion Air Preheat Temperature – Figure 4-51

- This histogram shows the extent to which recuperation technology is practised. The bin categories are in increments of 100°C, and these numbers on the x-axis indicate the maximum combustion air temperature for the group, e.g. the bar above 400°C shows that nine furnaces reported combustion air preheat temperatures between 300 and 400°C. It would be safe to assume that the nine furnaces reporting combustion air preheat temperatures below 100°C are not equipped with recuperation.
- Recuperation transfers heat from the furnace waste gas to the combustion air. The heat delivered to the furnace burners in the combustion air reduces the amount of fuel required to supply the furnace energy demand. Combustion air preheating increases flame temperature, which increases the rate of heat transfer in the furnace. This contributes to increased efficiency and may also increase furnace productivity.
- Preheating the combustion air increases the flame temperature, which is the main factor in the formation of NO_X. Since NO_X is a pollutant that contributes to acid deposition and smog formation, there are air-pollution-control-based limits for it. NO_X emissions can be held below regulatory limits by burner technology for combustion air preheats up to about 400°C. Above that temperature, the formation of NO_X increases rapidly, and costly end-of-pipe abatement equipment may be required. Hence, the feasibility of recuperation change and investing in more recuperation to raise combustion air temperature above 400°C may require trade-offs between energy efficiency, NO_X emissions and cost.
- Recuperation, in general, should be economically attractive for all reheating furnaces because:
  - Furnaces that charge cold steel into unfired preheat zones have low waste gas temperature. Therefore, recuperators are cheaper to install because they do not need to be constructed from expensive high-temperature materials. Also, since a portion of the waste gas heat has been removed in the unfired preheat zones, optimum furnace efficiency can often be achieved with combustion air preheat temperature below the 400°C break point.
  - Furnaces that hot charge will have high waste gas temperature, so high-cost, high-temperature materials will be required for recuperator construction. High-temperature waste gas produces high heat-transfer rates, which enable smaller recuperators to be installed for the same duty. Also, simple radiant heat transfer designs can be used. These factors make recuperators for high-temperature applications economically attractive.

Because of the differences in recuperator construction and service, before contemplating recuperation, plants should first establish to what extent they intend to implement a hot charging practice.

4.6.4 Unfired Charge Preheat Zone Length – Figure 4-52

- This histogram shows the extent to which furnaces are equipped with unfired charge preheat zones. The bin categories are in two-metre increments, and these numbers on the x-axis indicate the maximum length for the group, e.g. the bar above two metres shows that eight furnaces reported a charge preheat zone length between zero and two metres.
- The unfired preheat zone reduces energy consumption by decreasing the heat lost from the furnace in the waste gas. In the unfired preheat zone, the hot furnace waste gas flows countercurrent to the incoming cold steel so that the waste gas is cooled as heat is transferred to the steel. The effectiveness of this technology depends on the temperature difference between the furnace waste gas and the steel being charged into the furnace. Therefore, this technology is less effective with hot charging.

4.6.5 Furnace Average Charging Temperature – Figure 4-53

- This histogram shows the extent to which hot charging is practised. The bin categories are in increments of 100°C, and these numbers on the x-axis indicate the maximum average charge temperature for the group. For example, the bar above 100°C shows that 27 furnaces reported average charge temperature between 0°C and 100°C. It would be safe to assume that these furnaces are not using a hot charging practice.
- Hot charging reduces energy consumption by decreasing the amount of heat required to raise the temperature of the steel to rolling temperature. However, because the average temperature of the steel in the furnace is higher, the rate of heat transfer from the furnace gases to the steel is lower, which increases the waste gas temperature from the furnace. This can reduce furnace efficiency and decrease the gain expected from hot charging. Hence, hot charging will tend to nullify the benefits of an unfired preheat zone and increase the need for recuperation.
- Some grades of steel must be cooled after casting to produce the desired metallurgical properties.

5 POTENTIAL AREAS FOR INCREASED ENERGY EFFICIENCY

5. POTENTIAL AREAS FOR INCREASED ENERGY EFFICIENCY

5.1 Identifying Potential Areas for Reducing Energy Intensity

The key objective of this study is to compare benchmarks and technology penetration between plants and against international technology-based benchmark levels, thereby allowing areas of potential improvement to be identified. That has been accomplished by the results provided in Chapter 4. In all cases, those comparisons indicate a possible opportunity for one or more of the participating plants to reduce their energy intensity.

5.2 Factors for Reducing Energy Intensity Not Determined by This Study

The objectives for this study **do not** include quantifying the potential for reducing energy intensity. Chapter 4 benchmarked the energy intensity of the processes at the participating plants against those of the IISI EcoTech Plant. In every case, there are energy-intensity indicators for plants that are higher than those for the EcoTech Plant. It is tempting to view the gaps between the energy-intensity indicators for the plants and those of the EcoTech Plant as the potential for reducing energy intensity in the steel industry. However, that would produce a misleading result. For the following reasons, the actual potential for reducing energy intensity is much different:

1. The IISI EcoTech Plant represents a very energy-efficient practice and is considerably better (12 percent) than best practice today. As stated in Chapter 3, the EcoTech Plant is hypothetical, and its energy-intensity indicators are somewhat theoretical. Also, some process areas lack actual process and plant operating data to verify that they can be achieved in real life.

2. The economics of EcoTech Technologies depend on factors that differ from plant to plant and jurisdiction to jurisdiction. Moreover, the EcoTech Technologies are not necessarily fundamentally economically attractive.

3. It would also be unrealistic to expect that it would be feasible to implement all of the EcoTech Technologies at all plants. Some of the EcoTech Technologies are difficult or impossible to retrofit. It is doubtful that it would be economically feasible to abandon most existing facilities and replace them with new facilities incorporating the EcoTech Technologies.

4. The implementation of every technology and practice considered in this study involves capital expenditure. Fully implementing the EcoTech Technologies in the Canadian steel industry would require billions of dollars. The limited availability of capital within the steel industry and the number of priorities competing for the little capital that is available are most likely the controlling factors for the extent to which energy-saving technology will be implemented.

5. There are new processes for ironmaking and steelmaking that have potential for reducing cost and energy intensity. Some are in place in Canada (direct reduced iron production, cast-and-roll strip production), others are commercially available, and others are being developed. It would likely make business sense to invest in those technologies rather than attempting to upgrade existing facilities. However, the potential of these processes to reduce the energy intensity of iron and steel production is beyond the scope and mandate of this study.

6. The following factors, which are not considered in the EcoTech Plant performance, can significantly increase energy intensity:

   - Utilization of equipment: Energy intensity increases if equipment is not operated at or near design capacity, which is a reflection of the market and competition.
   - Product mix: The energy intensity will be higher for mills that produce a broad range of products because material losses and energy consumption occur during the period required to change over to the next product.
   - Climate: Energy intensity at Canadian mills will be greater because of the energy required to protect equipment and personnel from the harsh winter climate and to make up for greater process heat losses caused by low ambient temperatures.

For the above reasons, the results in Chapter 4 cannot be construed as indicating the real-life achievable energy-intensity reduction in the Canadian steel industry.

5.3 Identifying Areas of Greatest Potential

The results, as intended, identify areas of potential improvement in energy efficiency. Examining which EcoTech Technologies have been implemented in the Canadian steel industry, and which have not, provides some insight into which technologies might be most effective and feasible. To that end, the following focuses on areas where the potential to reduce energy intensity will likely be most realistic and achievable.

Practices and technologies with the potential to achieve more efficient use of energy for each process area are shown in the Energy and Technology figures for Chapter 4. They include all of the practices and technologies used to define the EcoTech Plant and some additional technologies and practices recommended by the CSPA participating plants. The penetration of those technologies was quantified for each plant and linked to their energy intensities.

Based on that information, the penetration of EcoTech Technologies can be summarized by the following:

1. Certain EcoTech Technologies in some process areas have not been implemented.
2. Some EcoTech Technologies have been implemented for each process in one or more plants.
3. Certain process areas, such as the EAF and the Blast Furnace, have a high degree of EcoTech Technology penetration.
4. Every process area has opportunities for one or more plants to reduce energy intensity by implementing EcoTech Technologies.
5. In some areas, such as steel reheating furnaces and power plants at integrated plants, the implementation of technology could significantly reduce energy intensity.
6. In some process areas, the variance in energy intensity between the participating plants cannot be explained by the penetration of technology and practices.

5.3.1 Areas Where the Implementation of Technology and Practice Are Unlikely

Certain EcoTech Technologies, in some process areas, have not been implemented. This could indicate that no plants have been able to justify implementing the technology. Possible reasons include:

1. The life of the process or the facility is seen to be too short to provide a return on investment.
    - An example is the lack of EcoTech Technology penetration in the cokemaking process area. Canadian cokemaking facilities are old, with limited life. (However, blast furnace technology to reduce dependence on coke has been implemented.) Coke is available on the world market from more modern facilities. Direct reduction and new smelt-reduction ironmaking technologies, which may replace aging blast furnaces, do not require coke.

2. The technology is not effective considering the design and operating characteristics of the existing facility.
    - An example is the lack of energy-recovery technology for blast furnace top gas. Canadian blast furnaces are designed for, and operate at, relatively low top-gas pressure. Hence, the amount of pressure energy to be recovered is less than for furnaces designed and operated with high top-gas pressure.

Some EcoTech Technologies have been implemented in one or more plants, but not the majority. This could indicate that not all plants could justify the technology. One possible reason is that the technology was not available or practical when the facility was built and is difficult or impossible to retrofit.

- An example is two BOF steelmaking facilities not equipped with gas recovery. They were built when the prevailing technology was to burn the off-gas and recover some of the heat in steam generation hoods. The cost of retrofitting a gas recovery system, and a system to deliver the recovered gas to users, is likely prohibitive.

- Another example is the unfired charge preheat zone length of a steel reheating furnace. To add an unfired charge preheating zone or to lengthen an existing one requires adding to the overall length of the furnace. That is often extremely difficult because the mills are laid out so that the furnace fits between the furnace charging equipment and discharging equipment. To accommodate a change in furnace length, the mill layout would need to be altered and equipment relocated, which would be costly and may not be possible.

5.3.2 Areas Where the Implementation of Technology and Practice Are Likely, but the Potential for Implementation Is Limited

Certain process areas have a high degree of EcoTech Technology penetration. This indicates that implementing EcoTech Technology is justifiable, and implementing the remaining technologies would likely be effective and feasible, based on broad success across the industry.

- One example is EAF steelmaking. The high penetration of technology in the EAF can be seen by looking at the Technology table in Figure 4-10, "Electric Arc Furnace Steelmaking and Casting – Energy and Technology," where eight EcoTech Technologies are apparent. Implementation of the eight technologies at the nine EAF facilities ranges from a minimum of five to a maximum of seven technologies, with an average of six. However, because of the high technology penetration, there is little left to be done. Oxygen blowing for post-combustion technology has been implemented on only one furnace. Implementing it on the remaining furnaces could result in a 5 percent reduction in energy intensity, which is about all the potential that remains.
- Another example is the use of fuel injection technology at the blast furnace to reduce dependency on coke. The high penetration of this technology can be seen by looking at the technology table in Figure 4-5, "Blast Furnace – Energy and Technology." Two furnaces have surpassed the EcoTech fuel injection rate of 3870 MJ per tonne of hot metal and have achieved the EcoTech coke rate of 361 tonnes of coke per tonne of hot metal. Also, the average fuel injection rate for all furnaces surpasses the EcoTech Plant performance, and the average coke rate is approaching that of the EcoTech Plant. The remaining industry-wide potential to lower coke dependency by achieving the EcoTech Plant performance at all furnaces is 27 kg of coke per tonne of hot metal. This goal should be pursued, but it is small compared with what has been achieved.

5.3.3 Areas Where the Implementation of Technology and Practice Are Likely, and the Potential for Lower Energy Intensity Is Great

In some areas, implementation of technology could significantly reduce energy intensity. In these areas, the technologies offer significant energy savings and can be readily implemented. These opportunities have most likely been studied and are well known to the participating plants. Other factors, such as availability of capital, competing priorities and external policy, have likely prevented the plants from pursuing these opportunities.

- An example is the power plant at integrated steel plants. The potential to reduce energy intensity at all the Canadian integrated steel plants is severely limited by inadequate power plant technology, as explained in Section 4.5.2.2. Based on the performance of the EcoTech Plant, Canadian integrated steel plants could produce enough electricity, without consuming any additional fuel, to approach being self-sufficient. Considering that all four integrated steel plants are in Ontario, where coal-fired electricity-generating plants are on the margin, the impact of the integrated plants generating that amount of electricity is immense. The order of magnitude of the savings could approach 2.7 million MWh per year of electrical energy, representing 2.3 million tonnes per year reduction in CO_2 emissions and $140 million in energy costs.

The EcoTech steam cogeneration power plant technology is mature, and there are no technical risks. It is in place throughout the world, including neighbouring states in the United States. A possible reason why this technology has not been implemented in Ontario (where all of the integrated plants are located) could be the province's electrical power generation policy. Other reasons include:

- Conflicting priorities at the steel plant (the power plant does not enhance productivity or product quality)
- Uncertain environmental policy
- Lack of capital (trade and tax issues)

There are certain areas where:

- Technology has been implemented in a sufficient number of Canadian steel plants to confirm that the EcoTech Plant performance is achievable.
- Implementing the technology in the remaining plants could significantly reduce energy intensity.

This situation leads one to the conclusion that, to remain competitive, all plants will eventually have to install the technologies and implement the practices.

- Reheating furnaces are an example of this situation. In the bloom and billet area, 33 percent of billet reheating furnaces are more efficient than the EcoTech Plant furnace, an indication that the EcoTech energy intensity can be achieved or surpassed. The energy intensity of four billet furnaces could be significantly reduced (by 20 to 25 percent) by implementing recuperation technology. It is also interesting that pusher furnaces can be as efficient as the EcoTech walking beam furnace because it is often necessary to install a new furnace to change from pusher to walking beam.
- In the area of slab reheating furnaces, the six slab furnaces equipped with most of the EcoTech Technologies approach the EcoTech efficiency, again an indication that the EcoTech energy intensity can be reached. The remaining 11 furnaces lack most, if not all, of the EcoTech Technologies and, accordingly, are extremely inefficient. Equipping these furnaces with the EcoTech Technologies (which in most cases would likely be best done by installing new furnaces) could reduce furnace energy intensity by 50 to 65 percent.

The steel industry and the participating plants can better determine which opportunities warrant their further investigation by categorizing all areas of opportunity according to the following:

- areas where the implementation of technology and practices are unlikely
- areas where the implementation of technology and practices are likely, but the potential for implementation is limited
- areas where the implementation of technology and practices are likely, and the potential for lower energy intensity is great

6 REFERENCES

6. REFERENCES

1. *Energy Use in the Steel Industry*, Committee on Technology, International Iron and Steel Institute, Brussels, 1998.

2. *European Steelworks Energy Committee Energy Reporting*, Yann de Lassat, Association Technique de la Sidérurgie Française, June 2001.

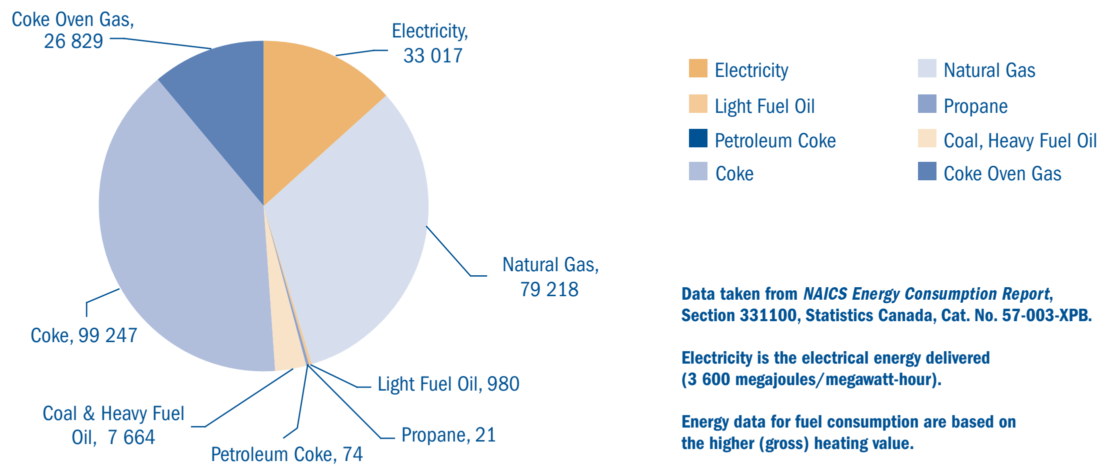
3. *Present and Future Use of Energy in the Canadian Steel Industry*, CANMET – Energy Mines and Resources Canada (now Natural Resources Canada), March 1993.

7

FIGURES, CHARTS AND TABLES

7. FIGURES, CHARTS AND TABLES

Figure 2-1. Iron and Steel Mills and Ferroalloy Manufacturing, 2002 Energy Consumption (Total: 247 050 terajoules)



Data taken from *NAICS Energy Consumption Report*, Section 331100, Statistics Canada, Cat. No. 57-003-XPB.

Electricity is the electrical energy delivered (3 600 megajoules/megawatt-hour).

Energy data for fuel consumption are based on the higher (gross) heating value.

Figure 2-2. EAF Plant Production – Flow Diagram

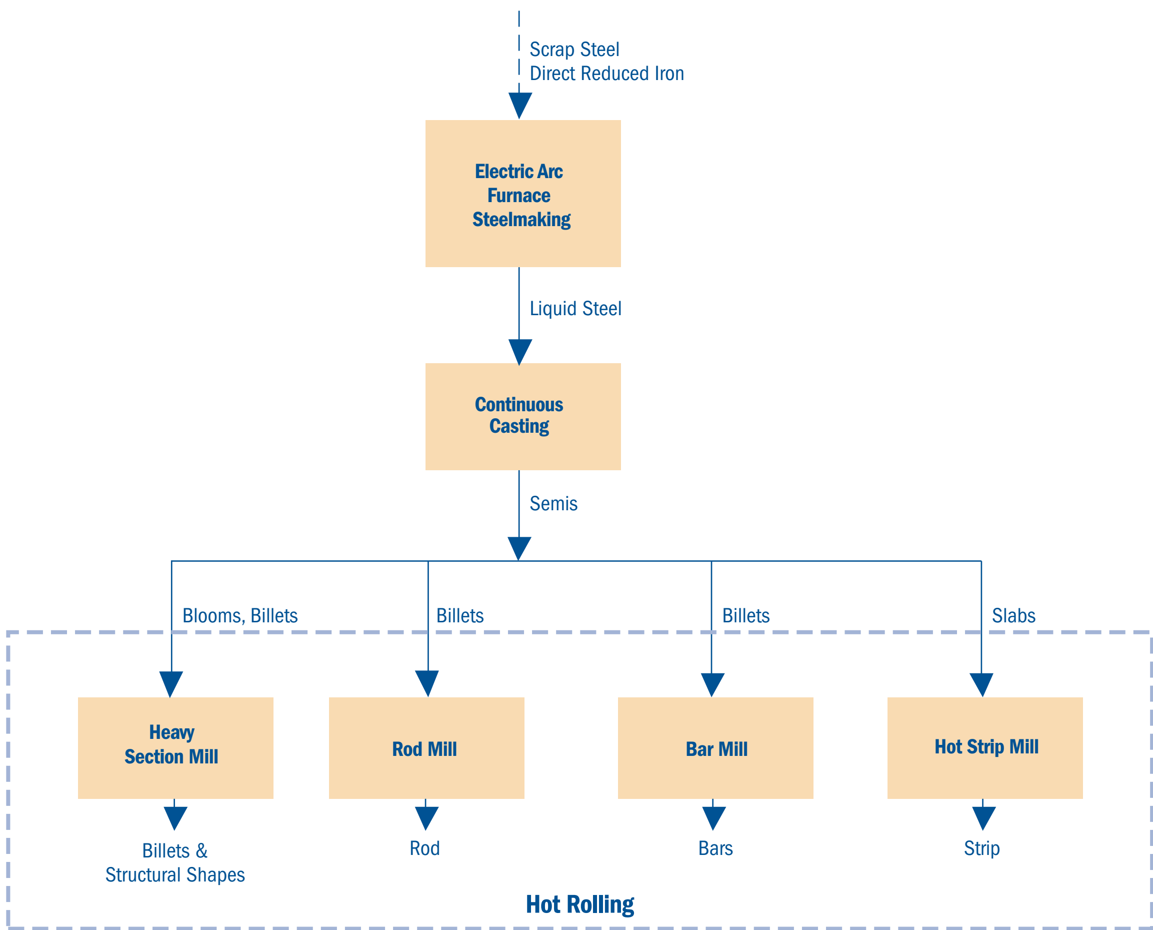
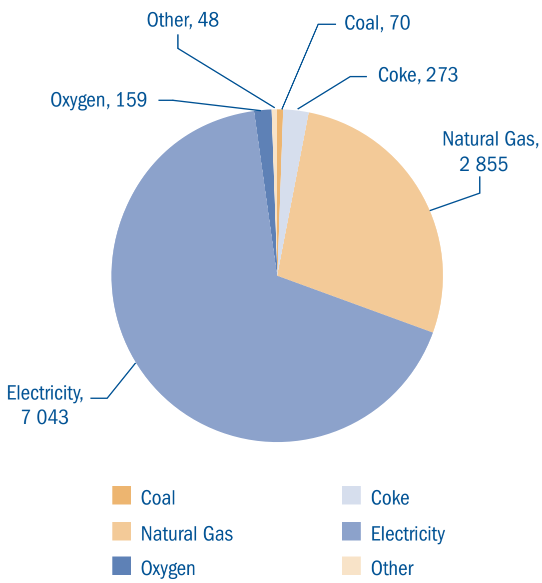


Figure 2-3. Energy-Intensity Indicator – EAF Plants, 2002 (MJ/tonne of Hot Rolled Product) (Total: 10 450 MJ/t)



All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 2-4. Integrated Plant Production – Flow Diagram

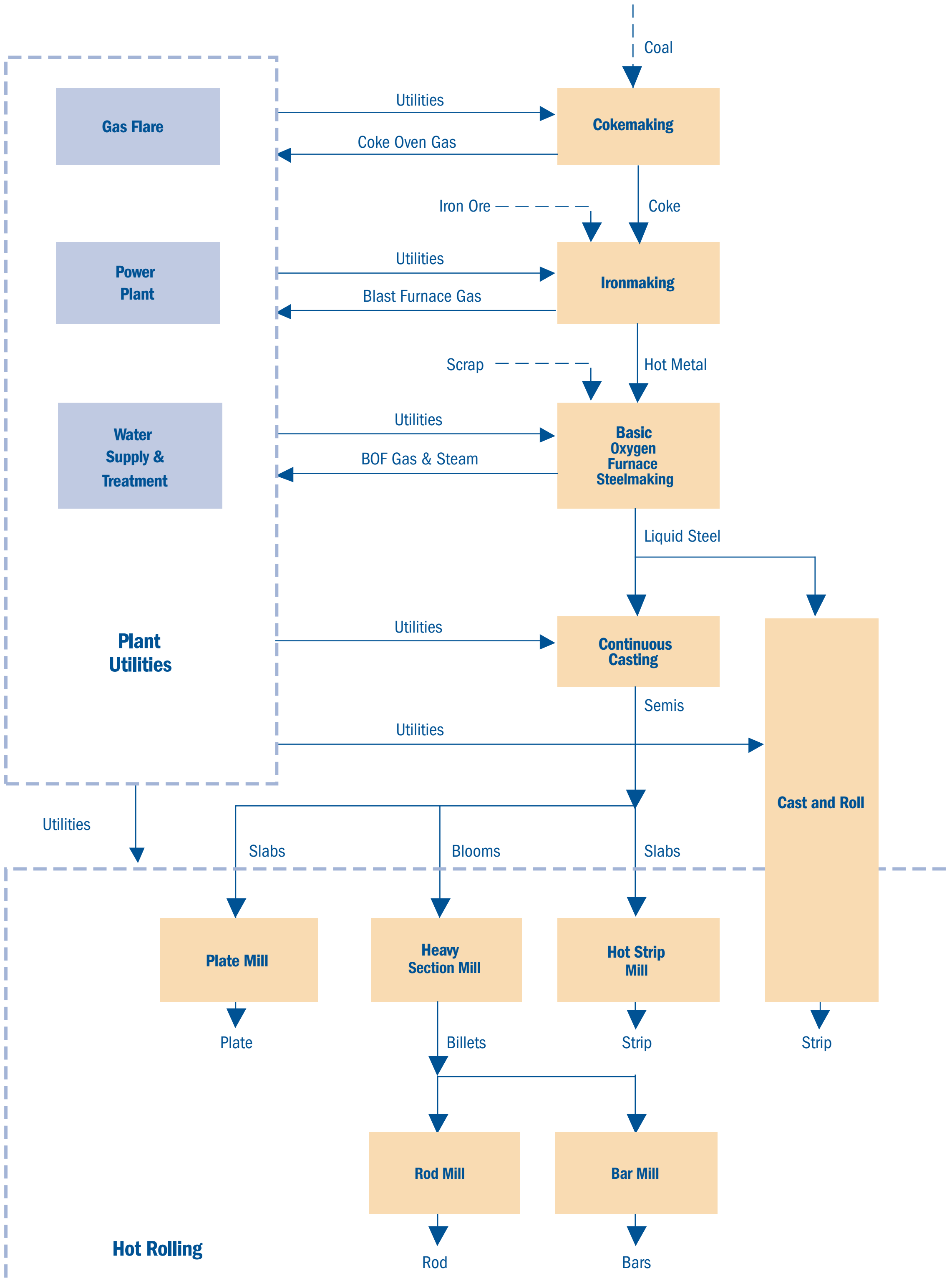
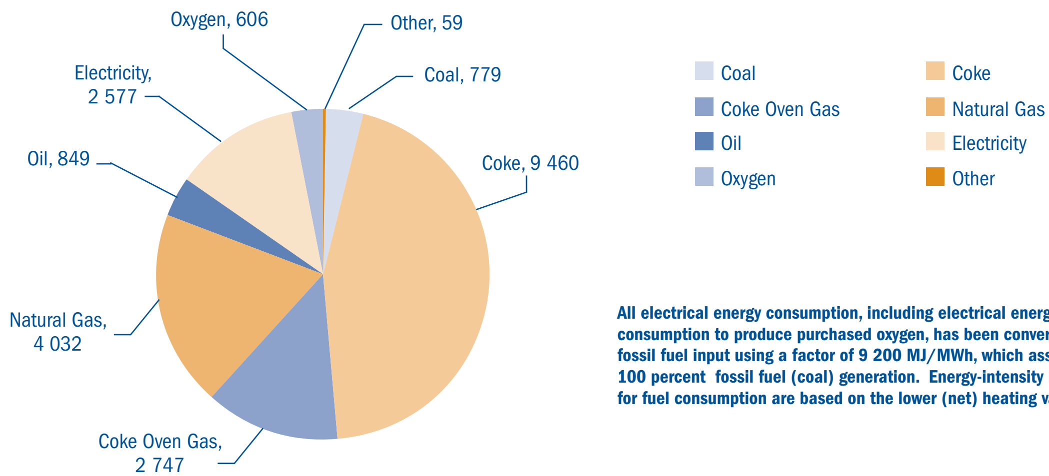
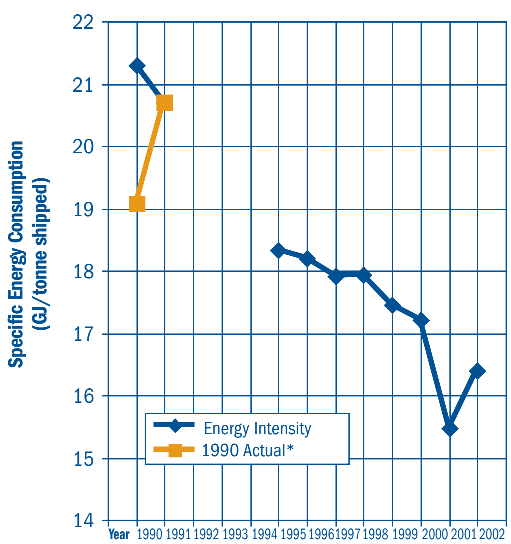


Figure 2-5. Energy-Intensity Indicator – Integrated Plants, 2002 (MJ/tonne of Hot Rolled Product) (Total: 21 050 MJ/t)



All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 2-6. Specific Energy Consumption (GJ/tonne shipped)



***1990 actual level is adjusted to remove the impact of labour disruptions.**

23 percent improvement in specific energy consumption from 1990 to 2002.

***Canadian Industry Program for Energy Conservation 2002/2003 Annual Report: Energy Ideas at Work*, page 72. ISBN 0-662-37418-5.**

Energy data for fuel consumption are based on the higher (gross) heating value.

Data missing for years 1992 to 1994 are not available from the referenced source.

Figure 3-1. EcoTech EAF Bar Plant

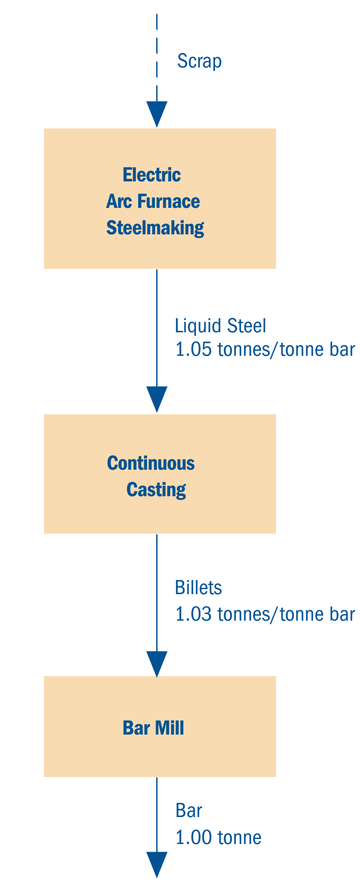
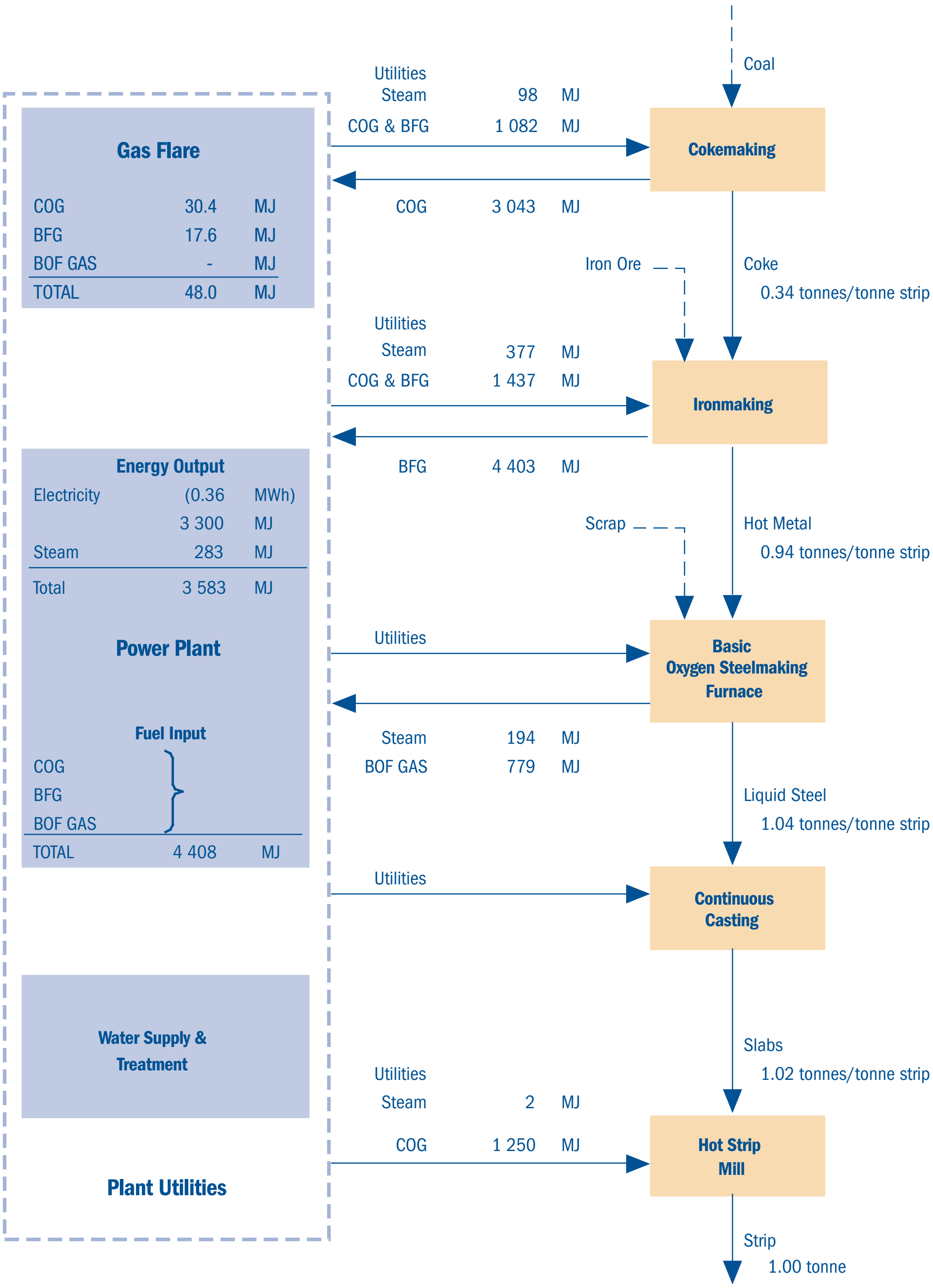
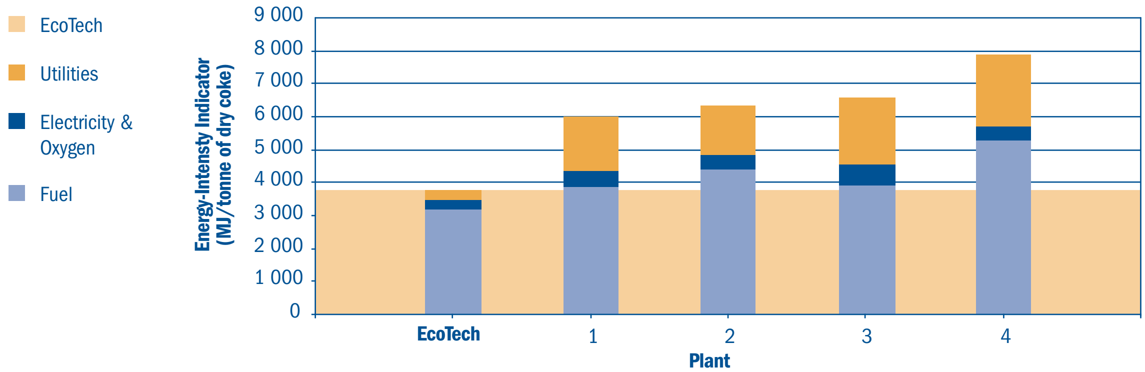


Figure 3-2. EcoTech Integrated Hot Strip Coil Plant and Utilities



Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-1. Cokemaking – Energy and Technology

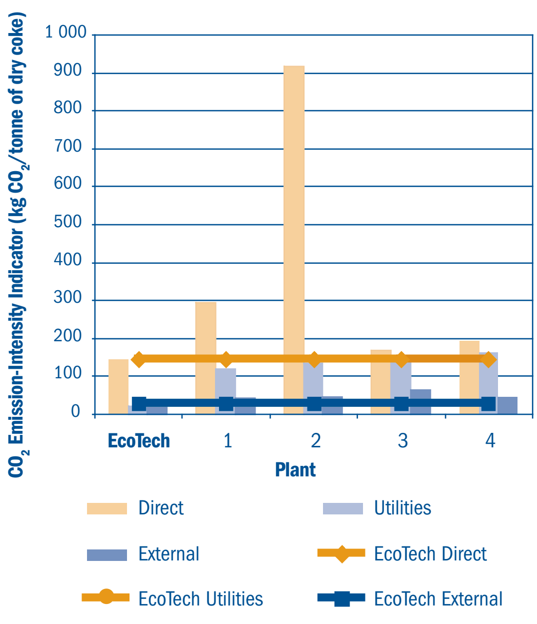


Technology or Practice

High-pressure ammonia liquor spray aspiration	EcoTech	No	No	No	Yes
Variable speed drives	EcoTech	Yes	No	No	Yes
Enhanced combustion control	CANMET	No	No	Yes	No
Coke dry quenching	AllTech	No	No	No	No
Coal drying	AllTech & CANMET	No	No	No	No
Coke oven gas sensible heat recovery	AllTech	No	No	No	No
Waste gas heat recovery	AllTech	Yes	Yes	No	Yes

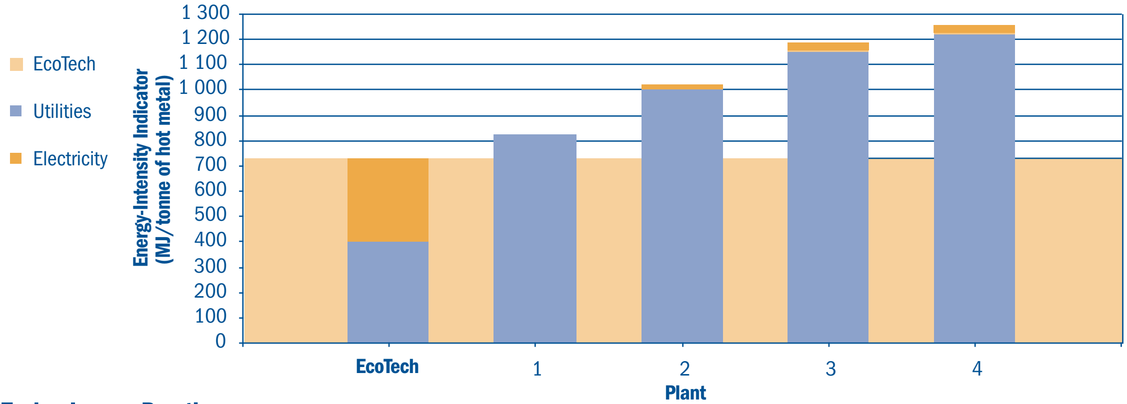
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-2. Cokemaking – CO_2



External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-3. Blowing – Energy and Technology

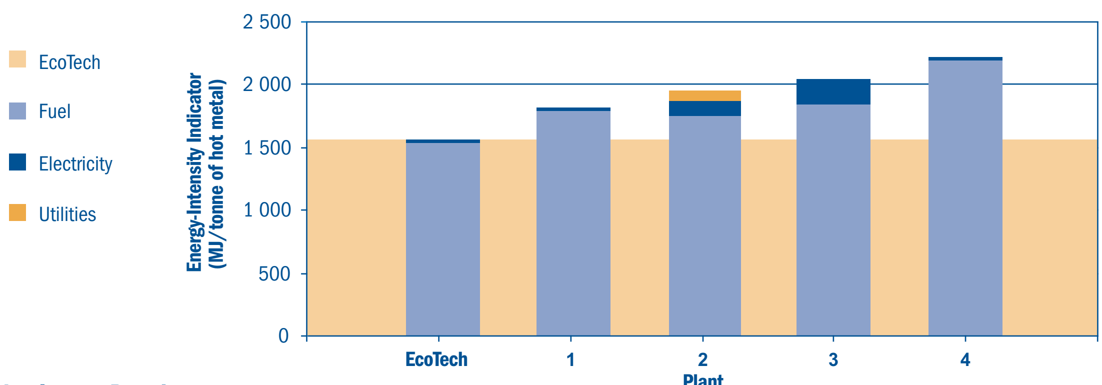


Technology or Practice

Axial blowers	EcoTech	no	yes	no	no
Oxygen enrichment of cold blast	EcoTech 35 Nm^3/thm	yes	yes	no	yes
	AllTech 50 Nm^3/thm	yes	yes	no	yes

All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-4. Stoves – Energy and Technology



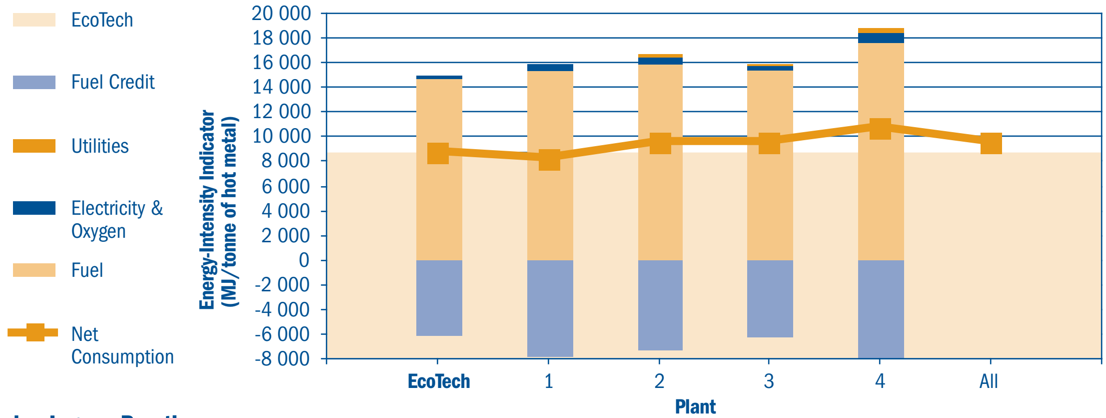
Technology or Practice

Waste gas heat recovery	EcoTech	no	yes	no	no
Staggered/parallel stove operation	EcoTech	no	no	no	no
Oxygen enrichment of cold blast	EcoTech	yes	yes	no	yes
Combustion control (<5% excess air)	EcoTech	10%	17%	10%	50%
Stove efficiency (85%)	EcoTech	78%	76%	78%	67%

Note: Plant 4 was operating with abnormally high excess air due to damaged stove burners. This mode of operation significantly decreases efficiency. Hence, the stove efficiency is below normal.

All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-5. Blast Furnace – Energy and Technology

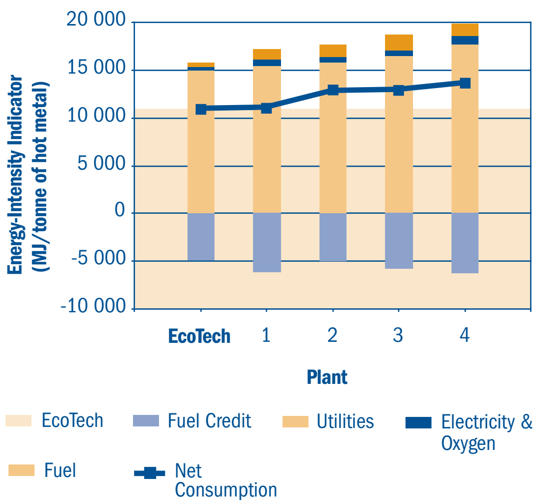


Technology or Practice

Top gas recovery turbine	EcoTech	no	no	no	no	
Blast furnace injectants						
Coke rate (kg/thm)	EcoTech 361	no	yes	no	yes	388
Injection rate (MJ/thm)	EcoTech 3 870	no	yes	no	yes	4 625
Casthouse emission control system	EcoTech 7.0	n/a	no	yes	n/a	

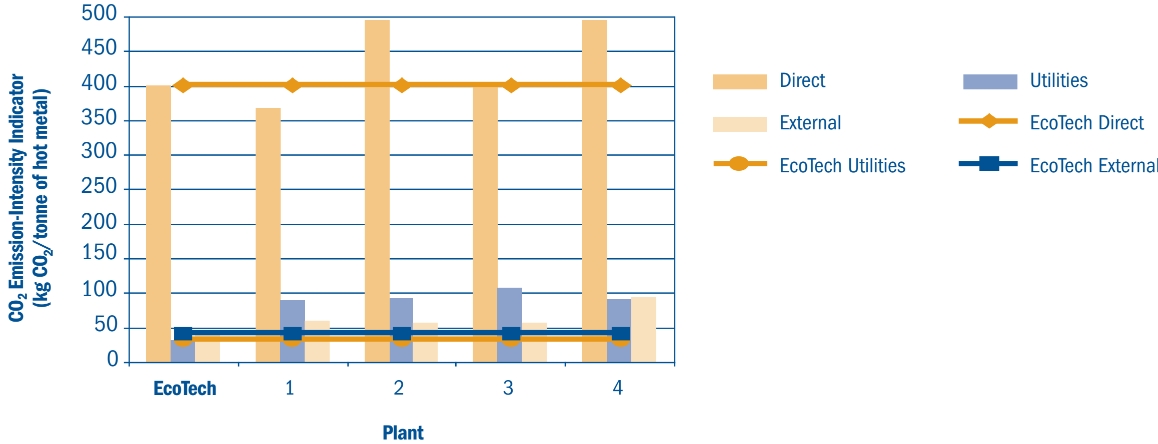
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-6. Ironmaking – Energy



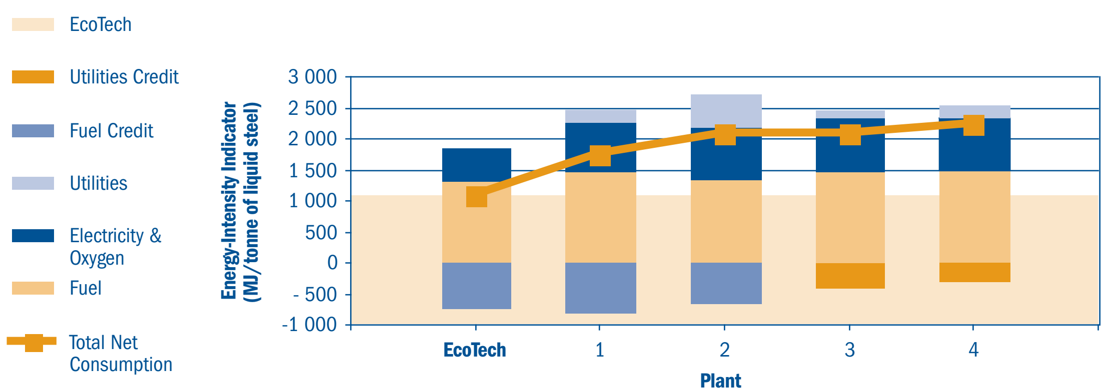
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-7. Ironmaking – CO_2



External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-8. Basic Oxygen Furnace Steelmaking – Energy and Technology

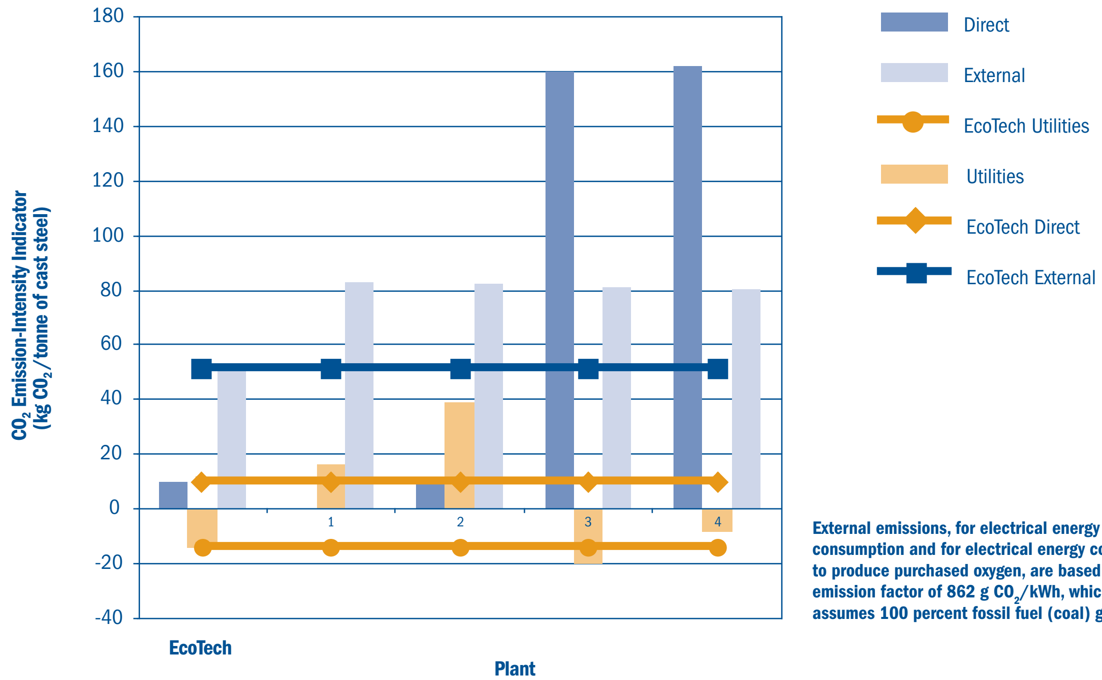


Technology or Practice

Gas recovery	**EcoTech**	**yes**	**yes**	**no**	**no**
Dry gas cleaning system		**no**	**no**	**no**	**no**
Expert system and gas pressure control		**no**	**no**	**no**	**no**
Steam recovery	**EcoTech**	**no**	**no**	**no**	**no**
Ladle management	**CANMET**				
Programmed ladle heating strategy		**yes**	**yes**	**yes**	**yes**
Waste heat recovery		**no**	**no**	**no**	**no**
Ladle lids used to reduce heat loss		**yes**	**yes**	**yes**	**yes**
Vessel bottom stirring	**CANMET**	**yes**	**no**	**no**	**no**
Single vessel operation		**yes**	**no**	**no**	**no**

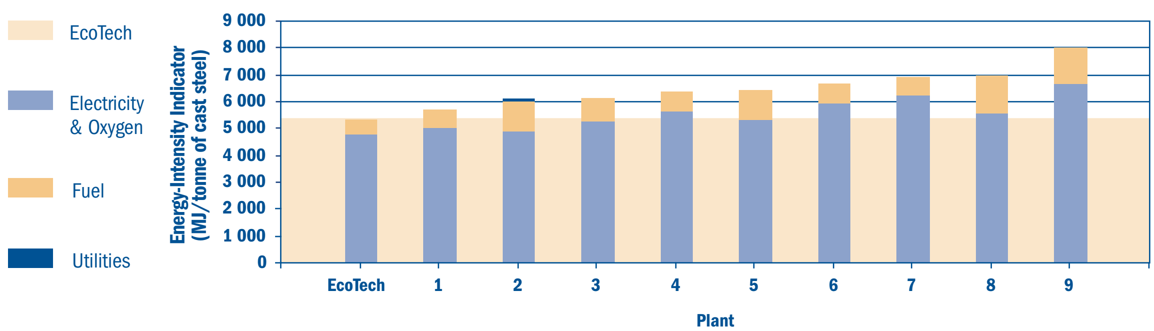
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-9. Basic Oxygen Furnace Steelmaking – CO_2



External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

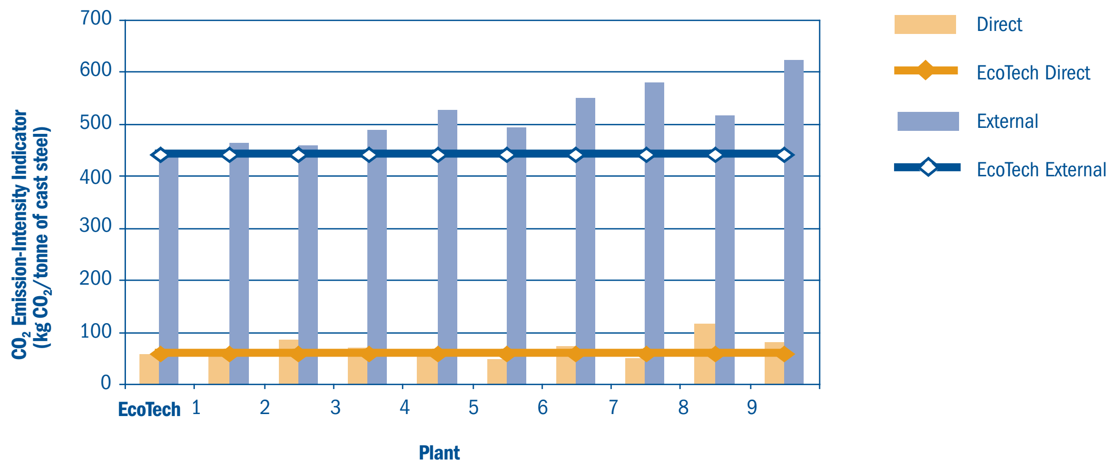
Figure 4-10. Electric Arc Furnace Steelmaking and Continuous Casting – Energy and Technology



Technology or Practice		1	2	3	4	5	6	7	8	9
Oxygen blowing for liquid steel oxidation	EcoTech	yes	yes	yes	yes	yes	yes	yes	yes	yes
Oxygen blowing for post combustion	EcoTech	no	no	no	no	yes	no	no	no	no
Oxy-fuel burners	EcoTech	yes	yes	yes	yes	yes	no	yes	yes	yes
Secondary metallurgy units	EcoTech	no	yes	yes	yes	yes	yes	yes	no	yes
Scrap preheating	AllTech	no	yes	no	no	no	no	no	no	no
Supplementary fuel (coal injection/charge)	EcoTech	yes	yes	yes	yes	yes	yes	no	no	yes
Water-cooled panels and roof	EcoTech	yes	yes	yes	yes	yes	yes	yes	yes	yes
Ultra-high-power AC transformer	EcoTech	yes	yes	no	yes	no	yes	yes	yes	yes
Eccentric bottom tapping	EcoTech	yes	no	no	yes	yes	yes	yes	yes	no
Level 1 and Level 2 controls	CSPA	no	yes	yes	yes	yes	yes	yes	yes	yes
Transformer tap changes	CSPA	yes	yes	yes	yes	no	yes	yes	yes	yes

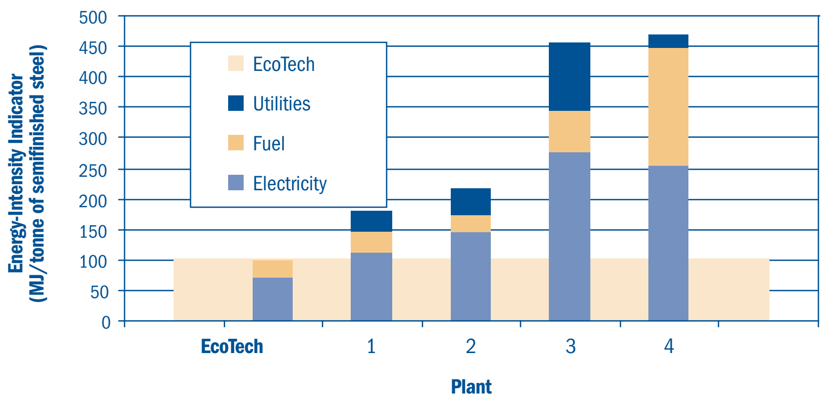
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-11. Electric Arc Furnace Steelmaking and Continuous Casting – CO_2



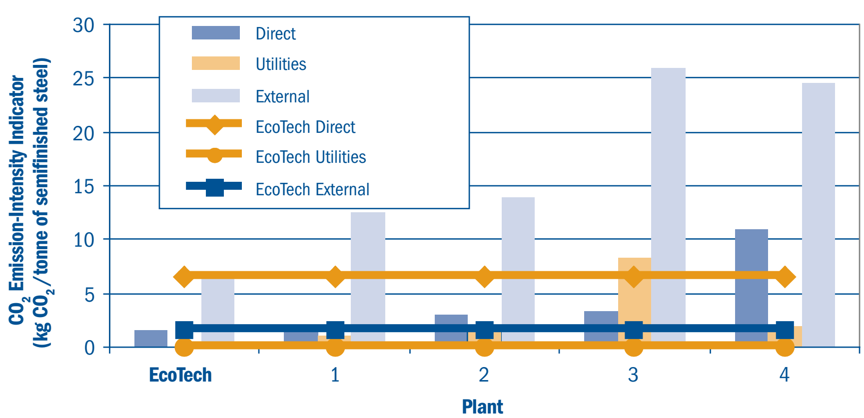
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-12. Continuous Casting – Energy



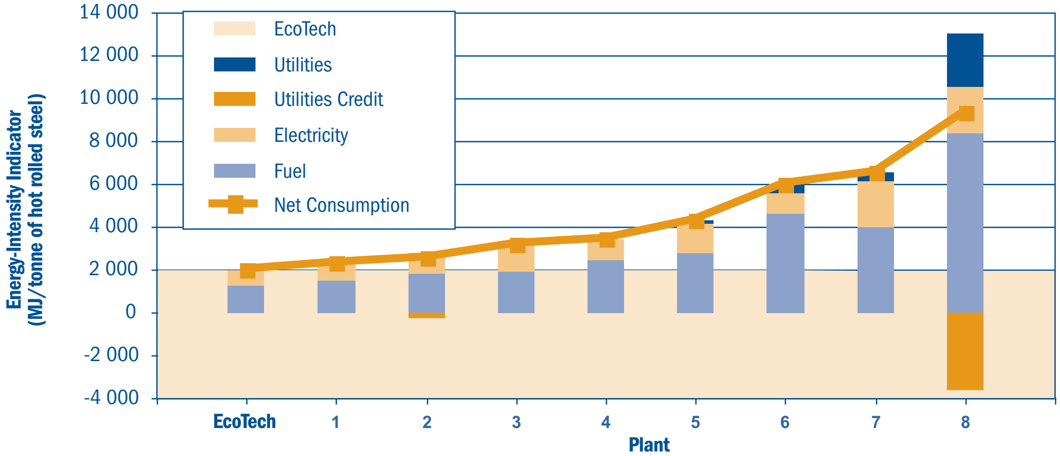
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-13. Continuous Casting – CO_2



External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-14. Hot Strip and Plate Mills – Energy and Technology

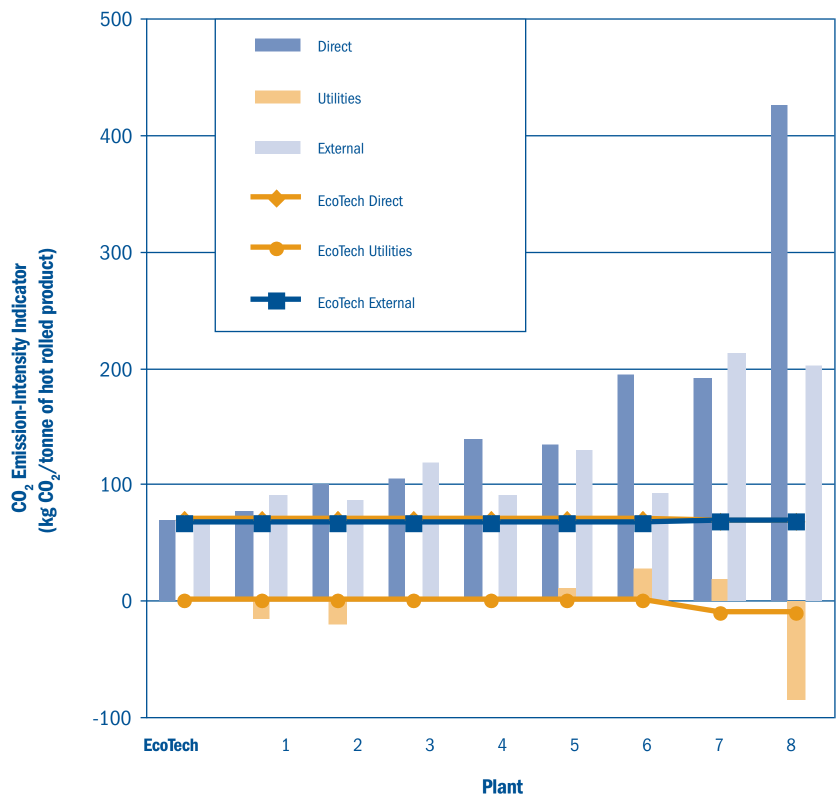


Technology or Practice

		1	2	3	4	5	6	7	8
Coilbox for transfer bar	**EcoTech**	**no**	**yes**	**no**	**yes**	**yes**	**yes**	**n/a**	**n/a**
Thermal covers on mill delivery and transfer tables	**EcoTech**	**yes**	**no**	**no**	**no**	**no**	**no**	**n/a**	**n/a**
Schedule-free rolling	**EcoTech**	**no**	**no**	**no**	**no**	**no**	**no**	**n/a**	**n/a**
Transfer bar edge heaters	**EcoTech**	**yes**	**no**	**no**	**no**	**no**	**no**	**n/a**	**n/a**
High edging facility	**EcoTech**	**medium**	**no**	**minimum**	**minimum**	**no**	**minimum**	**n/a**	**n/a**
AC roughing motor	**EcoTech**	**no**	**no**	**yes**	**no**	**no**	**no**	**n/a**	**n/a**

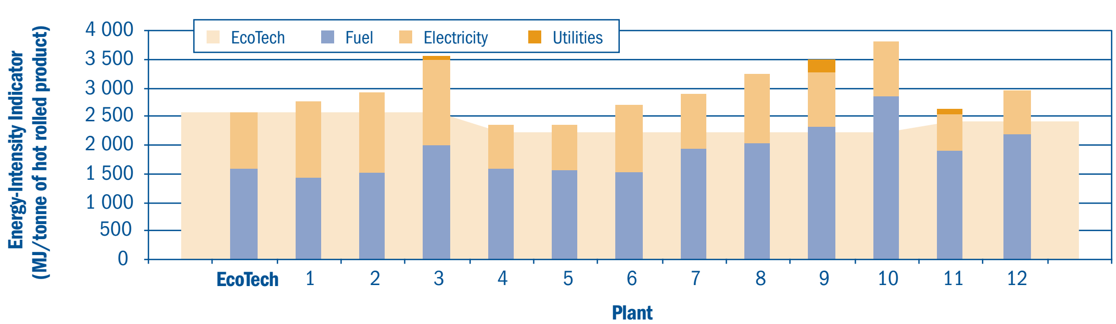
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-15. Hot Strip and Plate Mills – CO_2



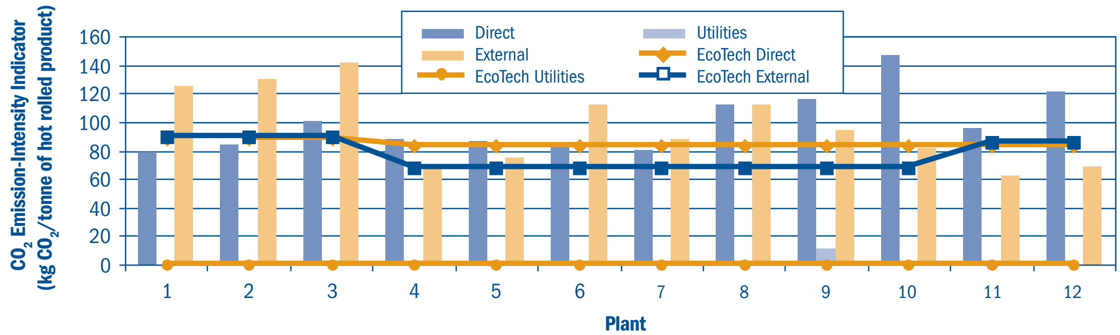
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-16. Section Mills – Energy



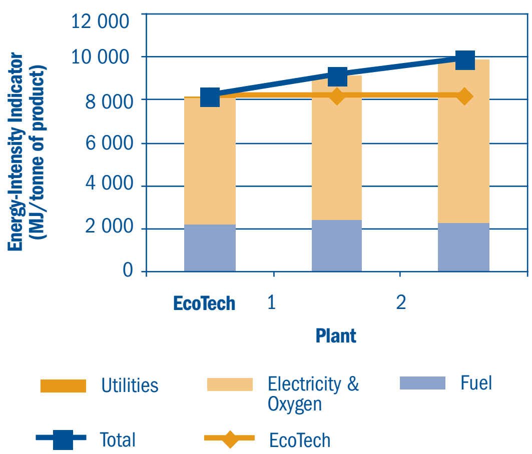
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-17. Section Mills – CO_2



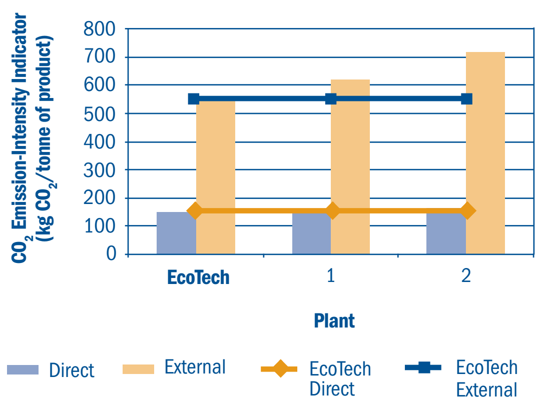
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-18. EAF Rod Plant – Energy



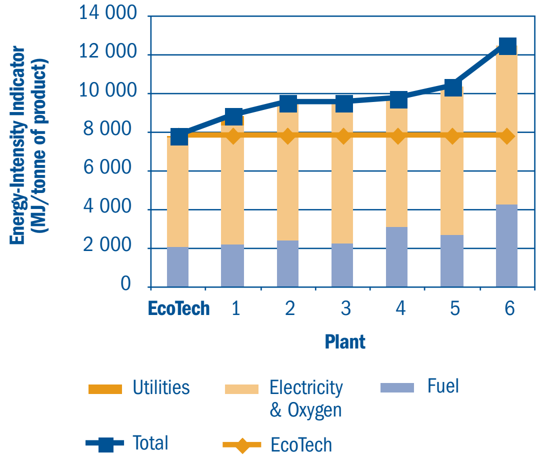
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-19. EAF Rod Plant – CO_2



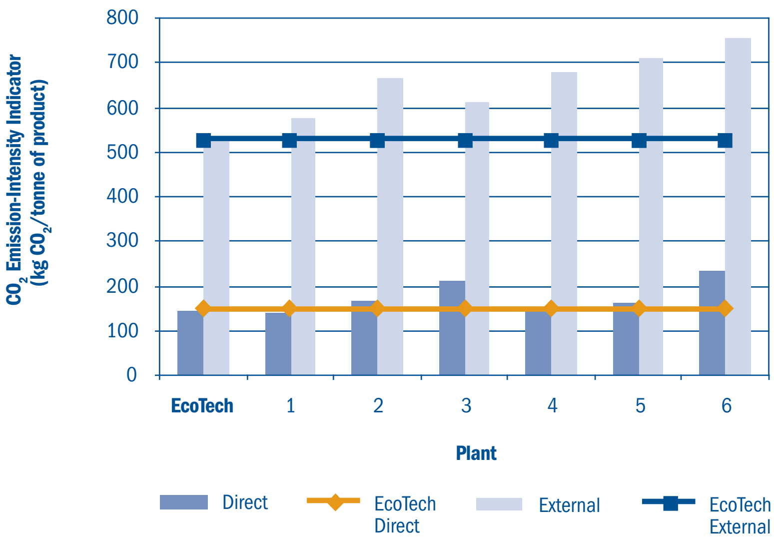
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-20. EAF Bar Plant – Energy



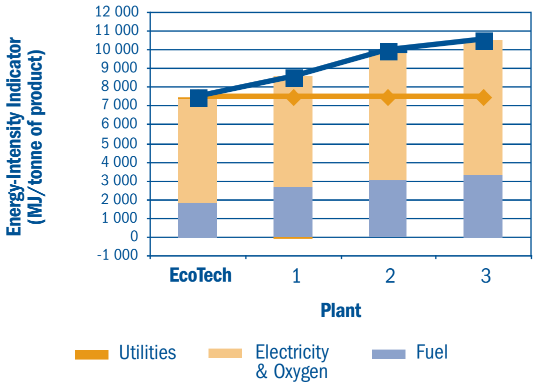
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-21. EAF Bar Plant – CO_2



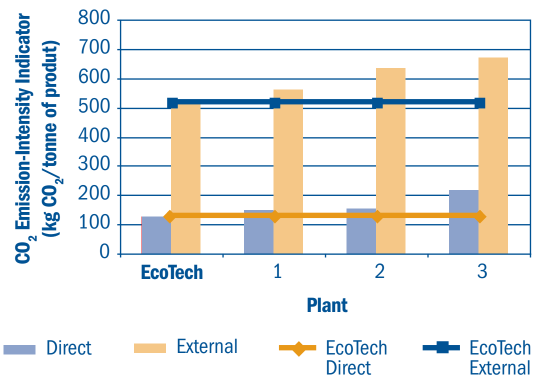
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-22. EAF Hot Strip Plant – Energy



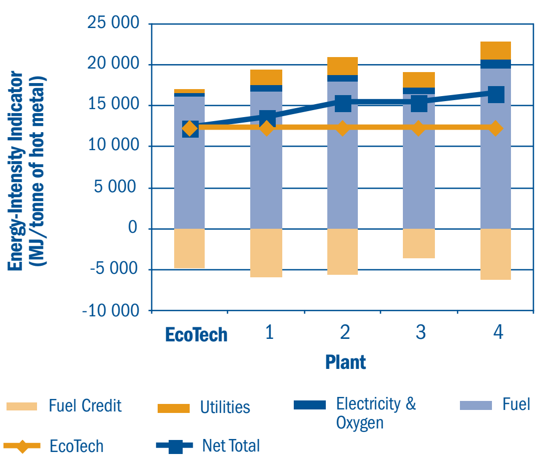
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-23. EAF Hot Strip Plant – CO_2



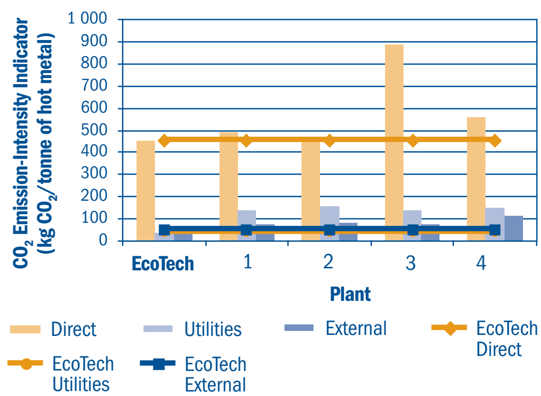
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-24. Integrated Iron Plant – Energy



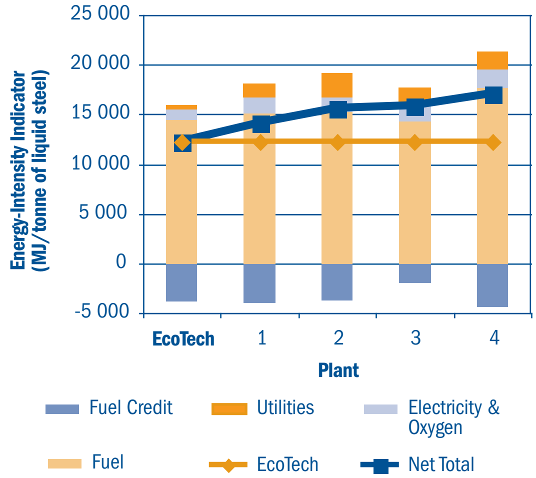
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-25. Integrated Iron Plant – CO_2



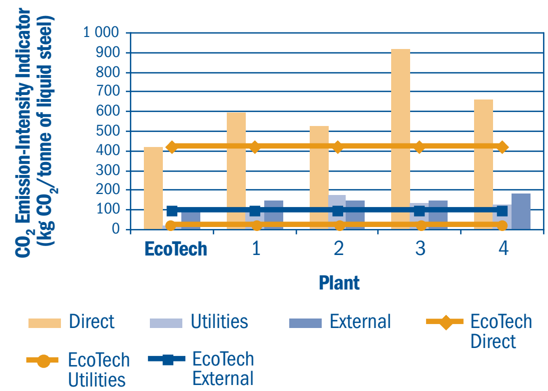
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-26. Integrated Steel Plant – Energy



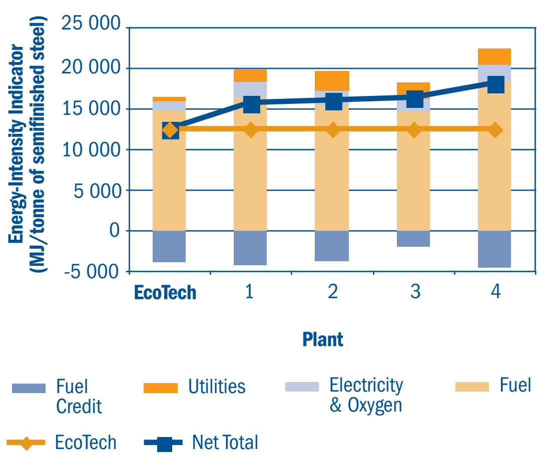
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-27. Integrated Steel Plant – CO_2



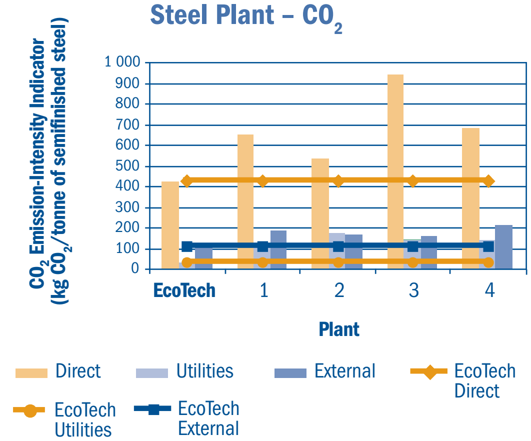
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-28. Integrated Semifinished Steel Plant – Energy



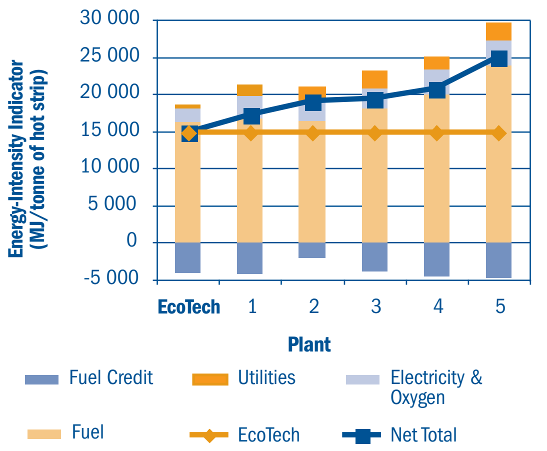
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-29. Integrated Semifinished Steel Plant – CO_2



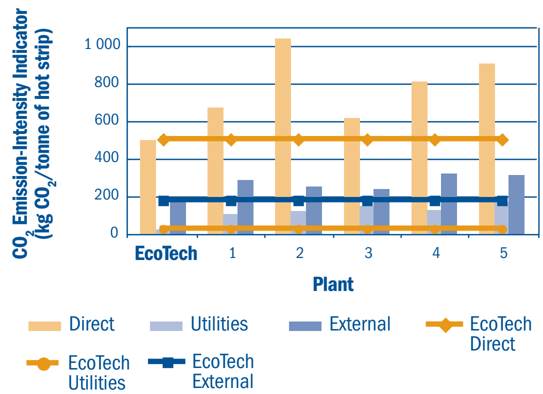
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-30. Integrated Hot Strip Plant – Energy



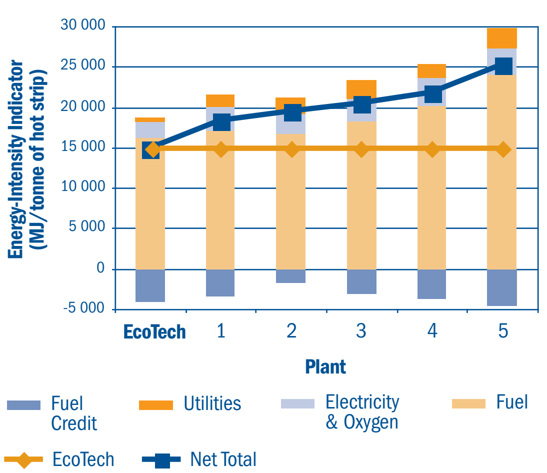
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-31. Integrated Hot Strip Plant – CO_2



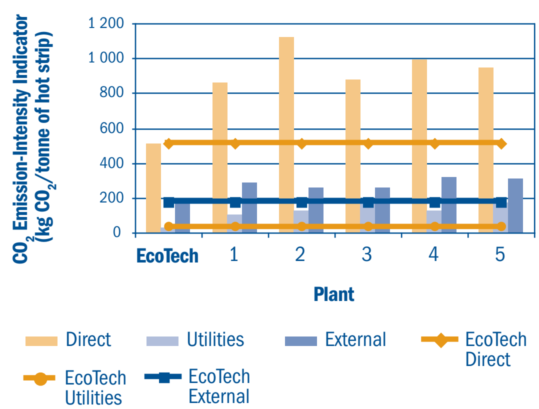
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-32. Integrated Hot Strip Plant – Energy (Including Gas Flare Allocation)



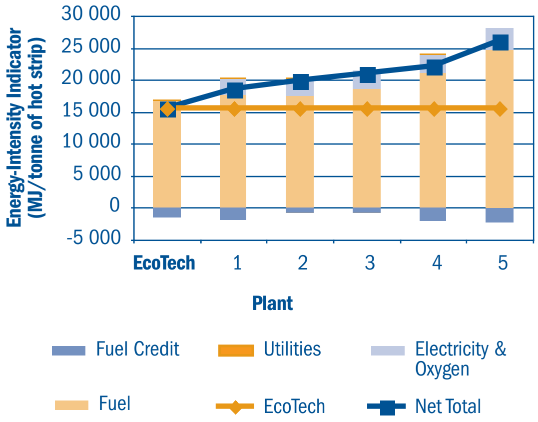
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-33. Integrated Hot Strip Plant – CO_2 (Including Gas Flare Allocation)



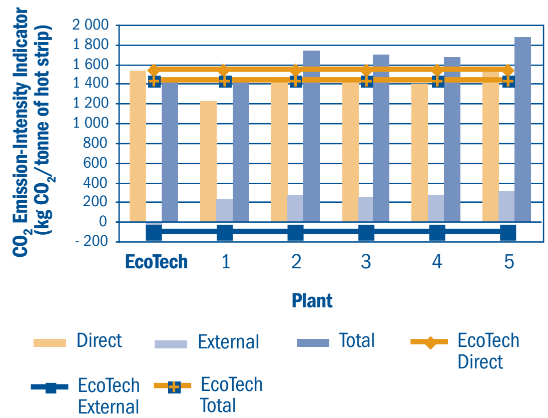
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-34. Integrated Hot Strip Plant – Energy (Including Gas Flare and Utilities Allocation)



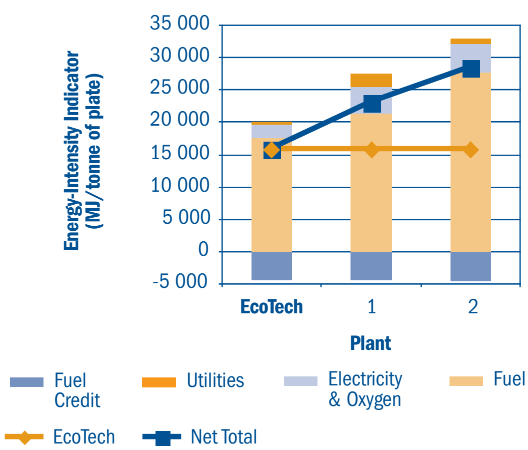
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-35. Integrated Hot Strip Plant – CO_2 (Including Gas Flare and Utilities Allocation)



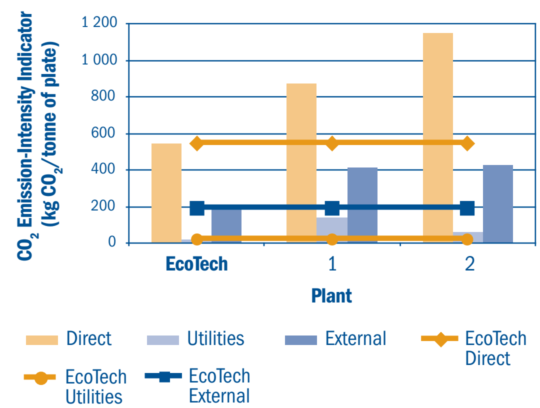
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-36. Integrated Plate Plant – Energy



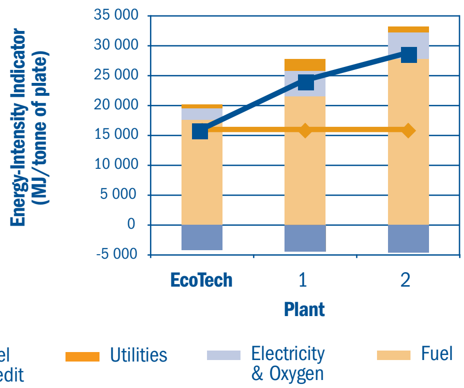
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-37. Integrated Plate Plant – CO_2



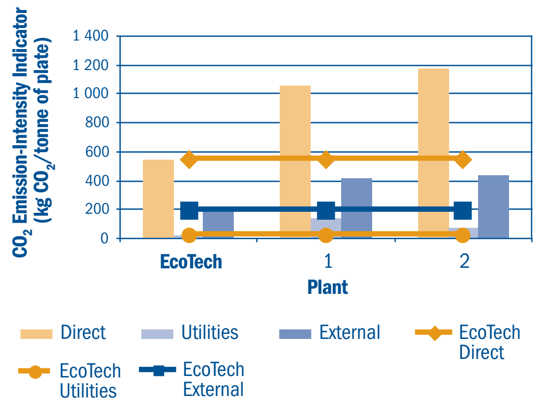
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-38. Integrated Plate Plant – Energy (Including Gas Flare Allocation)



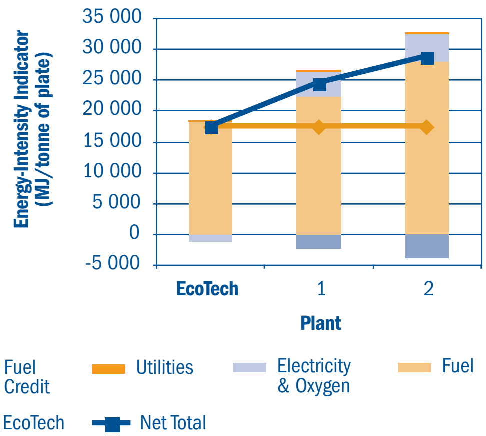
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-39. Integrated Plate Plant – CO_2 (Including Gas Flare Allocation)



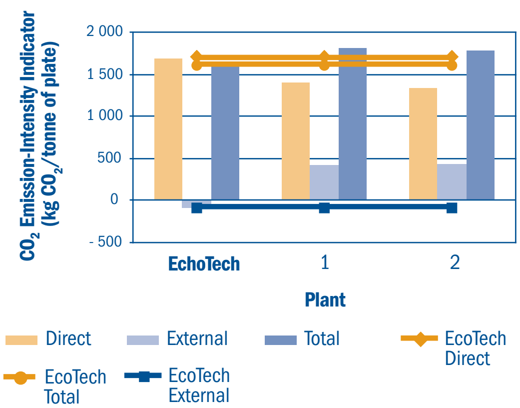
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-40. Integrated Plate Plant – Energy (Including Gas Flare and Utilities Allocation)



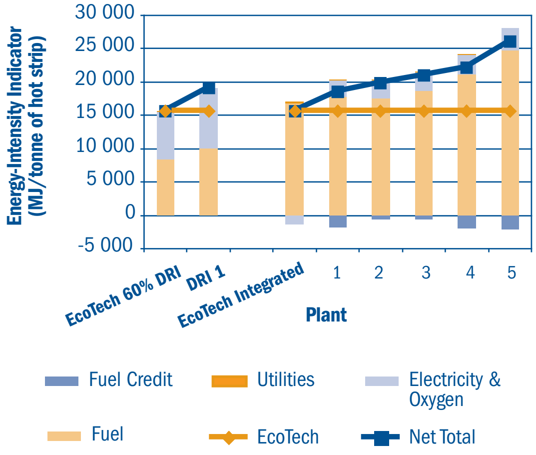
All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-41. Integrated Plate Plant – CO_2 (Including Gas Flare and Utilities Allocation)



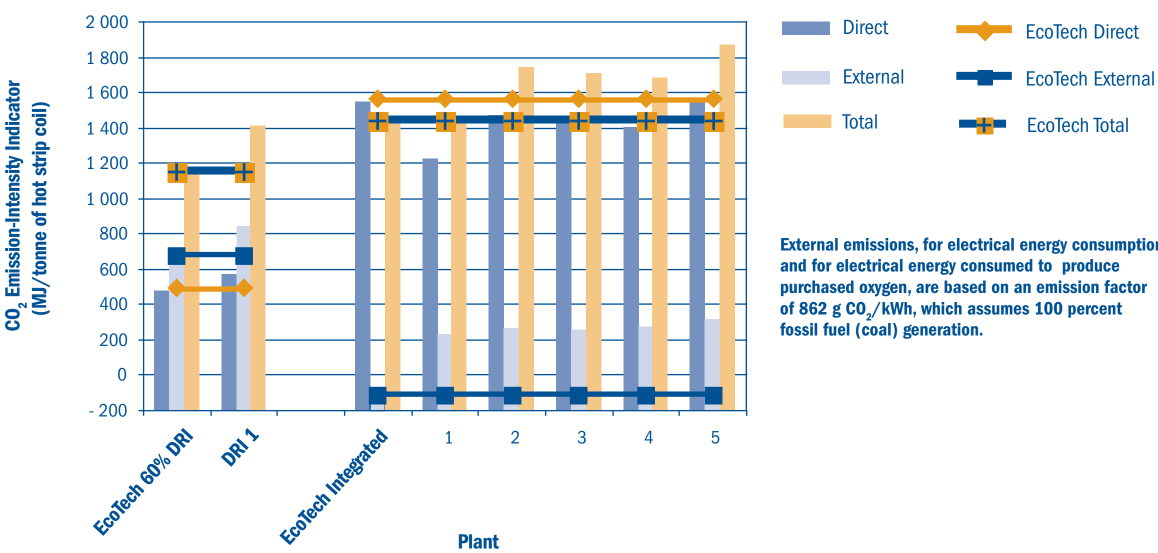
External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-42. Direct Reduced Iron and Integrated Hot Strip Plants — Energy



All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-43. Direct Reduced Iron and Integrated Hot Strip Plants — CO_2



External emissions, for electrical energy consumption and for electrical energy consumed to produce purchased oxygen, are based on an emission factor of 862 g CO_2/kWh, which assumes 100 percent fossil fuel (coal) generation.

Figure 4-44. Energy Monitoring

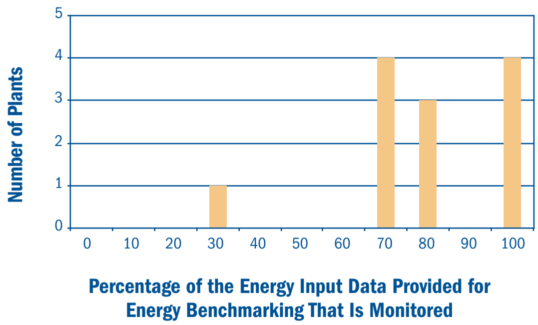


Figure 4-45. Energy Reporting

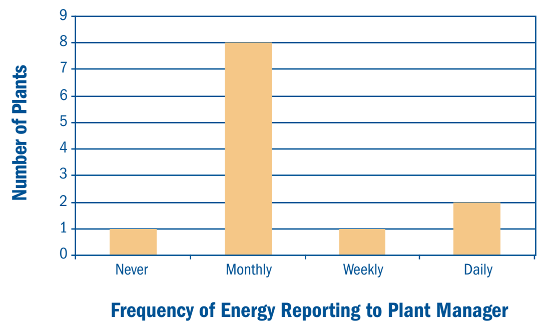
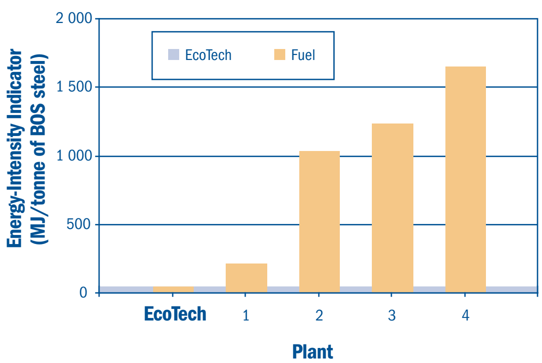


Figure 4-46. Gas Flares – Energy and Technology



Management of By-Product Fuel Utilization	1	2	3	4
Percentage of by-product fuel production and use that is continuously monitored	100	100	87	88
Percentage of by-product fuel flared that is continuously monitored	75	100	23	95
Percentage of time when purchased fuel is being fired and by-product fuel is being flared	75	60	40	100
Central automated or continuously staffed fuel dispatch system in place to maximize the use of by-product fuel	no	yes	yes	yes

Figure 4-47. Gas Flares – CO_2

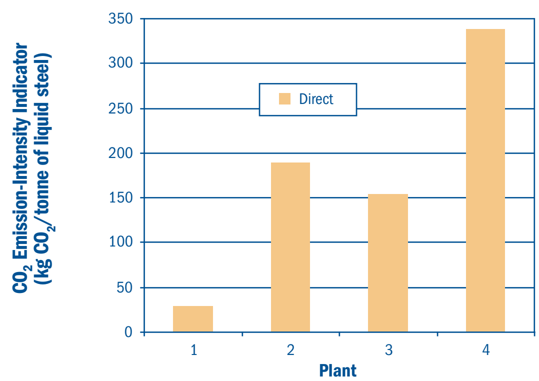
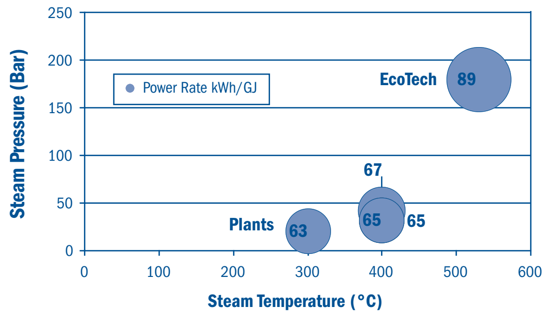


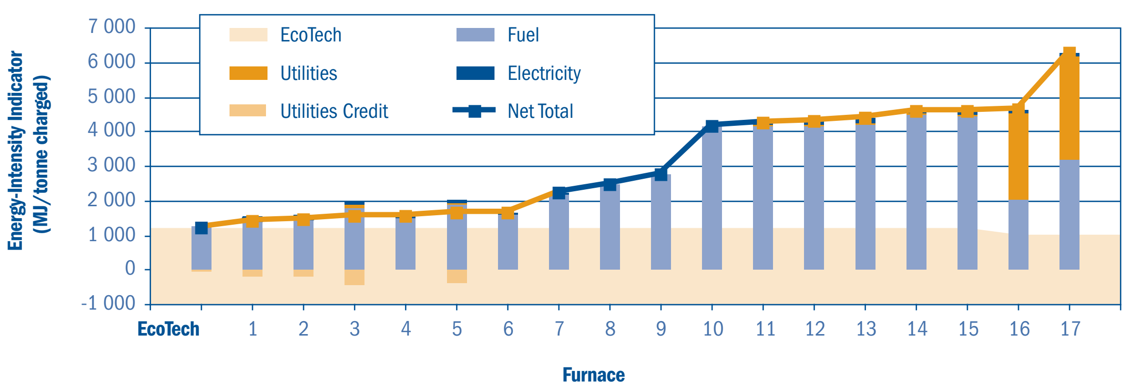
Figure 4-48. Power Plant – Performance and Technology



Technology or Practice	Plant				
	EcoTech	1	2	3	4
Steam Generation					
Pressure	180	42	32	32	21
Temperature (°C)	530	399	399	399	301
Electricity Generation					
MWh/t BOF steel	0.359	0.068	0.012	0	0
Technology					
Steam reheat stages	1	0	0	0	0
Regeneration stages	6	1	1	1	1
Performance					
Power rate (kWh/GJ)	89	67	65	65	63
Heat rate (MJ/kWh)	11.3	15.0	15.5	15.5	16.0

Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

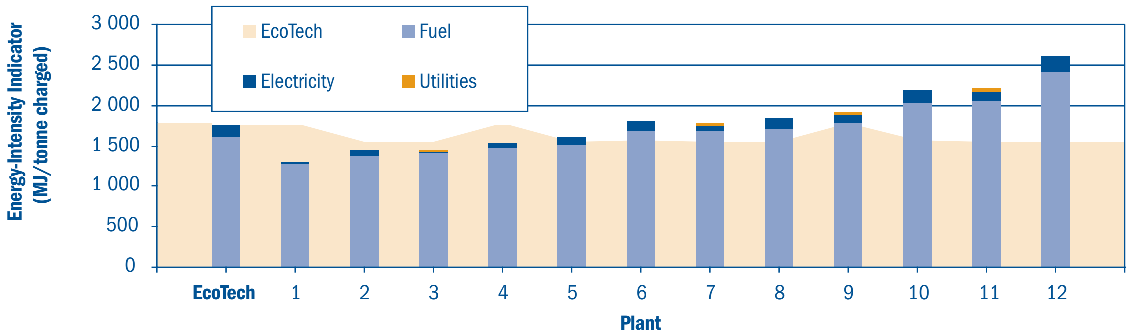
Figure 4-49. Slab Reheating Furnaces – Energy and Technology



Technology or Practice	EcoTech	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Furnace application		STRIP	STRIP	STRIP	STRIP	STRIP	STRIP	STRIP	P & S*	P & S*	P & S*	STRIP	STRIP	STRIP	STRIP	STRIP	PLATE	PLATE
Furnace type	Walking	Walking	Walking	Pusher	Walking	Walking	Pusher	Pusher	Walking	Walking	Walking	Pusher	Pusher	Pusher	Pusher	Pusher	Pusher	Pusher
Charge temperature (°C)	200	AMB**	AMB**	100	100	350	100	AMB**	AMB**	AMB**	AMB**	AMB**	AMB**	AMB**	AMB**	AMB**	AMB**	AMB**
Recuperation temperature (°C)	450	550	550	450	400	480	425	AMB**	315	371	AMB**	121	232	177	121	93	232	232
Charge preheat zone length (m)	10	8.8	8.8	6.76	10.82	9.14	6.76	3.4	10	0	0	12.192	7.9	7.0	12.2	7.0	8.7	8.7
Heat recovery steam boilers	AllTec	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	yes	yes
Skid cooling heat recovery	yes	yes	yes	yes	no	no	yes	no	0	0	0	no	no	no	no	no	no	no
Staggered or offset skids		yes	yes	yes	yes	no	yes	no	no	no	no	yes	yes	yes	yes	yes	yes	yes
Double insulated skids	AllTec	no	no	no	yes	no	no	no	no	yes	no	no	no	no	no	no	no	no
Level I control	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Level II control	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	no	no	no	no	yes	yes
Level III control	yes	yes	yes	no	no	no	no	yes	yes	yes	yes	no	no	no	no	no	yes	yes

All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value. *Plate and Strip (P&S) ** Ambient (AMB)

Figure 4-50. Billet and Bloom Reheating Furnaces – Energy and Technology



Technology or Practice	EcoTech	1	2	3	4	5	6	7	8	9	10	11	12
Furnace application		Rod Mill	Bar Mill	Bar Mill	Rod Mill	Bar Mill	Other	Bar Mill	Bar Mill	Rod Mill	Other	Bar Mill	Bar Mill
Furnace type	Walking	Pusher	Walking	Pusher	Walking	Pusher	Walking	Pusher	Walking	Pusher	Pusher	Walking	Walking
Charge temperature (°C)		ambient	ambient	ambient	ambient	ambient	564	ambient	ambient	ambient	ambient	ambient	ambient
Recuperation temperature (°C)	400	ambient	ambient	400	430	315	385	ambient	450	316	315	399	0
Charge preheat zone length (m)	yes	6.5	8.7	2	6	8.53	3	1.8	0	0	0	0	2.4
Heat recovery steam boilers		no	no	no	no	no	no	no	no	no	no	no	no
Skid cooling heat recovery		no	no	no	no	no	no	no	no	no	no	no	no
Staggered or offset skids		no	no	no	yes	no	no	no	no	no	no	yes	no
Double insulated skids		no	no	no	no	no	no	no	no	no	no	yes	no
Level I control		yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Level II control		yes	no	no	yes	yes	yes	yes	no	no	yes	yes	yes
Level III control		yes	no	no	yes	no	yes	no	no	no	no	yes	no

All electrical energy consumption, including electrical energy consumption to produce purchased oxygen, has been converted to fossil fuel input using a factor of 9 200 MJ/MWh, which assumes 100 percent fossil fuel (coal) generation. Energy-intensity indicators for fuel consumption are based on the lower (net) heating value.

Figure 4-51. Combustion Air Preheat Temperature

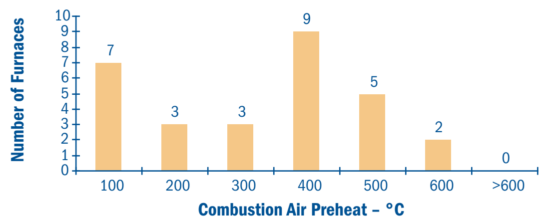


Figure 4-52. Unfired Charge Preheat Zone Length

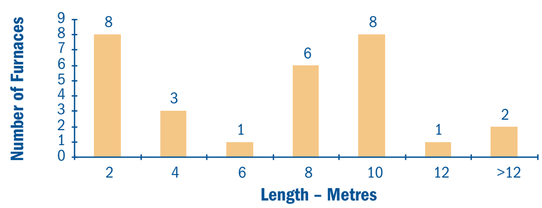
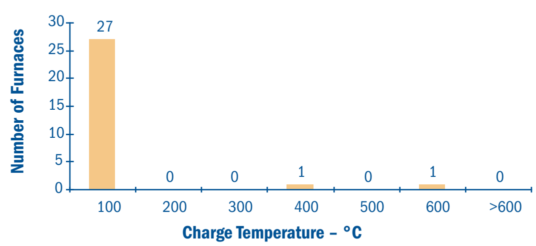


Figure 4-53. Furnace Average Charging Temperature



APPENDICES

APPENDIX A – ECOTECH TECHNOLOGIES AND ENERGY-INTENSITY AND CO_2 EMISSION-INTENSITY INDICATORS

COKEMAKING

			REFERENCES*
High-Pressure Ammonia Liquor Spray			
Aspiration		**EcoTech**	Page 36, Section 3.1.7
Variable Speed Drives		**EcoTech**	Page 36, Section 3.1.7
Coke Dry Quenching		**AllTech**	Page 36, Section 3.1.7
Coal Drying		**AllTech**	Page 36, Section 3.1.7
Enhanced Combustion Control		**CANMET**	
	ENERGY INTENSITY (MJ/tdc)	**CO_2 INTENSITY** (kg/tdc)	
Underfiring	3 200	144	Page 36, Section 3.1.7
Steam for By-Products Plant	290	21	Page 36, Section 3.1.7
Electricity	286	27	Page 36, Section 3.1.7
Total	**3 776**	**192**	

IRONMAKING

STOVES			REFERENCES
Waste Gas Heat Recovery		**EcoTech**	Page 64, Section 3.3.7.1
Staggered/Parallel Stove Operation		**EcoTech**	Page 64, Section 3.3.7.1
Oxygen Enrichment of Cold Blast			
35 m^3/tonne of hot metal		**EcoTech**	Page 64, Section 3.3.7.1
50 m^3/tonne of hot metal		**AllTech**	Page 64, Section 3.3.7.1
Combustion Control (5% Excess Air)		**EcoTech**	Page 64, Section 3.3.7.1
Stove Efficiency (Above 85%)		**EcoTech**	Page 64, Section 3.3.7.1
	ENERGY INTENSITY (MJ/thm)		
Blast Furnance Gas	1 303		Page 71, Table 7
Coke Oven Gas	231		Page 71, Table 7
Electricity	28		Page 68, Section 3.3.9
Total	**1 562**		

PULVERIZED COAL PREPARATION			REFERENCES
	ENERGY INTENSITY (MJ/thm)		
Electricity	18		Page 68, Section 3.3.9

*_Energy Use in the Steel Industry,_ Committee on Technology, International Iron and Steel Institute, Brussels, 1998.

BLOWERS			REFERENCES
Axial Blowers		**EcoTech**	Page 64, Section 3.3.7.2
	ENERGY INTENSITY (MJ/thm)		
Steam	402		
Electricity	328		Page 71, Table 7
Total	**730**		Page 71, Table 7

BLAST FURNACE			REFERENCES
Top Gas Recovery Turbine		**EcoTech**	Page 65, Section 3.3.7.3
Casthouse Emission Control System		**EcoTech**	Page 67, Section 3.3.9
7 kWh/thm			
Blast Furnace Injectants			
Coke Rate 361 kg/thm		**EcoTech**	Page 65, Section 3.3.7.3
Coke Rate 297 kg/thm		**AllTech**	Page 65, Section 3.3.7.3
	ENERGY INTENSITY (MJ/thm)		
Coke	10 827		Page 71, Table 7
Oil	1 320		Page 71, Table 7
Coal	2 550		Page 71, Table 7
Natural Gas	-		
Steam	-		
Electricity	184		Page 68, Section 3.3.9
Oxygen	209		Page 71, Table 7
Other	-		
Carbon	(1 443)		Page 65, Section 3.3.7.3
Blast Furnace Gas	(4 700)		Page 71, Table 7
Electricity	(166)		Page 71, Table 7
Net Total	**8 781**		

TOTAL FOR IRONMAKING	ENERGY INTENSITY (MJ/thm)	CO_2 INTENSITY (kg/thm)	REFERENCES
Coke	10 827	1 167	Page 71, Table 7
Oil	1 320	103	Page 71, Table 7
Coal	2 550	236	Page 71, Table 7
Natural Gas	-	-	
Coke Oven Gas (Stoves)	231	10	Page 71, Table 7
Blast Furnace Gas (Stoves)	1 303	365	Page 71, Table 7
Blast Furnace Gas (Credit)	(4 700)	(1 316)	Page 71, Table 7
Steam (Blowing)	402	33	Page 71, Table 7
Electricity	230	21	Page 68, Section 3.3.9
Electricity (Blowing)	328	30	Page 68, Section 3.3.9
Electricity (Credit)	(322)	(30)	Page 71, Table 7
Oxygen	209	19	Page 71, Table 7
Carbon	(1 443)	(165)	Page 65, Section 3.3.7.3
Net Total	**10 935**	**473**	

BASIC OXYGEN FURNACE (BOF) STEELMAKING			REFERENCES
Gas Recovery with Dry Gas Cleaning System		**EcoTech**	Page 78, Section 3.4.7
Steam Recovery		**CANMET**	
Ladle Management		**CANMET**	
Vessel Bottom Stirring		**CANMET**	
Single Vessel Operation		**CANMET**	
Yield	900	kg hm/tls	Page 78, Section 3.4.7
	ENERGY INTENSITY (MJ/tls)	**CO_2 INTENSITY** (kg/tls)	
Oxygen	311	29	Page 78, Section 3.4.7
Electricity	239	22	Page 78, Section 3.4.7
Other	172	-	Page 78, Section 3.4.7
Carbon	1 299	148	Page 78, Section 3.4.7
Steam (Credit)	(186)	(14)	Page 78, Section 3.4.7
BOF Gas (Credit)	(748)	(138)	Page 78, Section 3.4.7
Net Total	**1 087**	**47**	

CONTINUOUS CASTING

			REFERENCES
Yield	0.98		Page 78, Section 3.4.7
	ENERGY INTENSITY (MJ/tcs)	**CO_2 INTENSITY** (kg/tcs)	
Electricity	71	7	Page 78, Section 3.4.7
Other	30	2	Page 78, Section 3.4.7
Total	**101**	**9**	

ELECTRIC ARC FURNACE (EAF) STEELMAKING

	ENERGY INTENSITY (MJ/tls)	**CO_2 INTENSITY** (kg/tls)	REFERENCES
Electricity	4 361	406	Page 91, Section 3.5.7.1
Oxygen	222	21	Page 91, Section 3.5.7.1
Natural Gas	158	9	Page 91, Section 3.5.7.1
Carbon	414	47	Page 91, Section 3.5.7.1
Total	**5 155**	**483**	IS 5079 on Page 91

EAF (STEELMAKING) and CONTINUOUS CASTING

	ENERGY INTENSITY (MJ/t)		
	EAF	**CASTING**	**EAF and CASTING**
Material Input t/t (=1/Yield)		1.020	
Electricity	4 361	71	4 519
Oxygen	222		226
Natural Gas	158	30	191
Carbon	414		422
Total	**5 155**	**101**	**5 359**

	CO_2 INTENSITY (kg/tcs)		
	EAF	**CASTING**	**EAF and CASTING**
Electricity	406	7.0	421
Oxygen	21		21
Natural Gas	9		9
Carbon	47		48
Other		2.0	
Total	**483**	**9.0**	**500**

NOTE:
To produce one tonne of cast steel requires an input of 1 020 kg of liquid steel. Therefore, the energy-intensity indicator for EAF and Casting = 1.02 x the energy intensity indicator for EAF + energy-intensity factor for Casting.

HOT STRIP MILL

			REFERENCES
Coilbox for Transfer Bar		**AllTech**	Page 116, Table 10
Thermal Covers on Mill Delivery and Transfer Tables		**EcoTech**	Page 116, Table 10
Schedule-Free Rolling		**EcoTech**	Page 116, Table 10
Transfer Bar Edge Heaters		**EcoTech**	Page 116, Table 10
High Edging Facility		**AllTech**	Page 116, Table 10
AC Roughing Motor		**EcoTech**	Page 116, Table 10
(also see Slab Reheating Furnaces)			
Yield	0.98		Page 115, Table 9
	ENERGY INTENSITY (MJ/thrs)	**CO_2 INTENSITY** (kg/thrs)	
Natural Gas	1 250	69	Page 108, Section 3.6.7
Electricity	721	67	Page 108, Section 3.6.7
Other	5	1	Page 108, Section 3.6.7
Steam	37	3	Page 108, Section 3.6.7
Recovered Energy Credit	(35)	(3)	Page 108, Section 3.6.7
Net Total	**1 978**	**137**	

PLATE MILL

			REFERENCES
(see Slab Reheating Furnaces)			Page 120, Section 3.7.6
Yield	0.9		Page 121, Table 1
	ENERGY INTENSITY (MJ/thrs)	**CO_2 INTENSITY** (kg/thrs)	
Fuel	1 229	68	Page 120, Section 3.7.6
Electricity	730	68	Page 120, Section 3.7.6
Recovered Energy Credit	(150)	(11)	Page 120, Section 3.7.6
Net Total	**1 809**	**125**	

SECTION MILLS

LIGHT SECTION (ROD) MILL			REFERENCES
(see Billet Reheating Furnaces)			Page 131, Section 3.8.7.3
Yield	0.96		Page 133, Table 3
	ENERGY INTENSITY (MJ/thrs)	**CO_2 INTENSITY** (kg/thrs)	
Natural Gas	1 600	89	Page 131, Section 3.8.7.3
Electricity	966	90	Page 131, Section 3.8.7.3
Total	**2 566**	**179**	

MEDIUM SECTION (BAR) MILL			REFERENCES
(see Billet Reheating Furnaces)			Page 130, Section 3.8.7.2
Yield	0.97		Page 132, Table 2
	ENERGY INTENSITY (MJ/thrs)	**CO_2 INTENSITY** (kg/thrs)	
Natural Gas	1 500	83	Page 130, Section 3.8.7.2
Electricity	736	68	Page 130, Section 3.8.7.2
Total	**2 236**	**151**	

HEAVY SECTION (BLOOM and STRUCTURAL) MILL			REFERENCES
(see Billet Reheating Furnaces)			Page 130, Section 3.8.7.1
	ENERGY INTENSITY (MJ/thrs)	**CO_2 INTENSITY** (kg/thrs)	
Natural Gas	1 500	83	Page 130, Section 3.8.7.1
Electricity	920	86	Page 130, Section 3.8.7.1
Total	**2 420**	**169**	

SLAB REHEATING FURNACES

HOT STRIP MILL FURNACES			REFERENCES
Average Charge Temperature (200°C)		**EcoTech**	Page 108, Section 3.6.7
Recuperation		**EcoTech**	Page 116, Table 10
Charge Preheat Zone Length (10 m)		**EcoTech**	Page 116, Table 10
Heat Recovery Steam Boilers			
Skid Cooling Heat Recovery		**EcoTech**	Page 116, Table 10
Staggered or Offset Skids			
Double-Insulated Skids		**AllTech**	Page 116, Table 10
Level I Control		**EcoTech**	Page 116, Table 10
Level II Control		**EcoTech**	Page 116, Table 10
Level III Control		**EcoTech**	Page 116, Table 10
	ENERGY INTENSITY (MJ/thrs)		
Natural Gas	1 250		Page 108, Section 3.6.7
Electricity	17		Page 108, Section 3.6.7
Recovered Energy Credit	(35)		Page 108, Section 3.6.7
Net Total	**1 232**		

PLATE MILL FURNACES			REFERENCES
Average Charge Temperature (300°C)		**EcoTech**	Page 120, Section 3.7.6
Recuperation Temperature (450°C)		**EcoTech**	Page 120, Section 3.7.6
Charge Preheat Zone Length (10 m)			
Heat Recovery Steam Boilers			
Skid Cooling Heat Recovery		**EcoTech**	Page 120, Section 3.7.6
Staggered or Offset Skids			
Double-Insulated Skids			
Level I Control			
Level II Control			
Level III Control			
	ENERGY INTENSITY (MJ/thrs)		
Fuel	1 010		Page 120, Section 3.7.6
Electricity	150		Page 120, Section 3.7.6
Recovered Energy Credit	(150)		Page 120, Section 3.7.6
Net Total	**1 010**		

BILLET AND BLOOM REHEATIING FURNACES

LIGHT SECTION (ROD) MILL FURNACE	**ENERGY INTENSITY** MJ/thrs		REFERENCES
Total Fuel	1 600		Page 131, Section 3.8.7.3
Electricity	175		Page 135, Table 6
Total	**1 775**		
MEDIUM SECTION (BAR) MILL FURNACE	**ENERGY INTENSITY** MJ/thrs		REFERENCES
Total Fuel	1 500		Page 130, Section 3.8.7.2
Electricity	55		Page 134, Table 5
Total	**1 555**		
HEAVY SECTION (STRUCTURAL) MILL FURNACE	**ENERGY INTENSITY** MJ/thrs		REFERENCES
Total Fuel	1 500		Page 130, Section 3.8.7.1
Electricity	64		Page 134, Table 4
Total	**1 564**		

GAS FLARES	**ENERGY INTENSITY**	**CO_2 FACTOR**	
COKE OVEN GAS	MJ/tdc	kg CO_2/MJ	AVERAGE OF REPORTED NUMBERS
COG Credit	9 000		REASONABLE FOR ONE-BATTERY PLANTS
1% for Reversals	90	0.045	
BLAST FURNACE GAS	MJ/thm		REFERENCES
Top Gas Credit	4 700		Page 71, Table 7
Max. Bleed of 0.4%	18.8	0.28	Page 235, Section 6.3.2
BOF GAS	MJ/tls		REFERENCES
GAS Credit	748		
Max. Bleed of 0.4%	2.99	0.185	Page 235, Section 6.3.2

APPENDIX B – CO_2 EMISSION FACTORS

CO_2 EMISSION FACTORS

Carbon	3 664	kg CO_2/t	32 066	MJ/t	0.114	kg CO_2/MJ
Coal	3 000	kg CO_2/t	32 373	MJ/t	0.093	kg CO_2/MJ
Coke	3 227	kg CO_2/t	29 951	MJ/t	0.108	kg CO_2/MJ
Coke Oven Gas	45	kg CO_2/GJ	-	kJ/Nm^3	0.045	kg CO_2/MJ
Blast Furnace Gas	280	kg CO_2/GJ	-	kJ/Nm^3	0.280	kg CO_2/MJ
Basic Oxygen Furnace Gas	185	kg CO_2/GJ	-	kJ/Nm^3	0.185	kg CO_2/MJ
Other Ironmaking Gas	-	kg CO_2/GJ	0	kJ/Nm^3	-	kg CO_2/MJ
Natural Gas	56	kg CO_2/GJ	37 000	kJ/Nm^3	0.056	kg CO_2/MJ
Liquefied Petroleum Gas	-	-	-	-	-	kg CO_2/MJ
Heavy Oil	3 170	kg CO_2/t	40 569	MJ/t	0.078	kg CO_2/MJ
Light Oil	3 170	kg CO_2/t	-	MJ/t	-	kg CO_2/MJ
High Pressure Steam	267	kg CO_2/t	3 300	MJ/t	0.081	kg CO_2/MJ
Medium Pressure Steam	240	kg CO_2/t	3 200	MJ/t	0.075	kg CO_2/MJ
Low Pressure Steam	224	kg CO_2/t	3 100	MJ/t	0.072	kg CO_2/MJ
Electricity	856	g CO_2/kWh	9 200	kJ/kWh	0.093	kg CO_2/MJ
Oxygen	556	g CO_2/Nm^3	650	Wh/Nm^3	0.093	kg CO_2/MJ
Nitrogen	171	g CO_2/Nm^3	200	Wh/Nm^3	0.093	kg CO_2/MJ
Compressed Air	103	g CO_2/Nm^3	120	Wh/Nm^3	0.093	kg CO_2/MJ
Industrial Water	86	g CO_2/km^3	100	Wh/m^3	0.093	kg CO_2/MJ

Electricity	856 kg/MWh	REFERENCE	Page 254, Section 7.8

NOTE: Year average numbers for Ontario Hydro Energy range from
850 to 890 kg/MWh depending on coal, oil and natural gas mix.

ABBREVIATIONS IN APPENDIX A

Abbreviation	Name
MJ/tdc	megajoules per tonne of dry coke
kg/tdc	kilograms per tonne of dry coke
MJ/thm	megajoules per tonne of hot metal
kg/thm	kilograms per tonne of hot metal
kWh/thm	kilowatt hours per tonne of hot metal
kg hm/tls	kilograms of hot metal per tonne of liquid steel
MJ/tls	megajoules per tonne of liquid steel
kg/tls	kilograms per tonne of liquid steel
t/t	tonne per tonne
MJ/tcs	megajoules per tonne of cast steel
kg/tcs	kilograms per tonne of cast steel
MJ/thrs	megajoules per tonne of hot rolled steel
kg/thrs	kilograms per tonne of hot rolled steel
kg CO_2/MJ	kilograms of carbon dioxide per megajoule

ABBREVIATIONS IN APPENDIX B

Abbreviation	Name
kg CO_2/t	kilograms of carbon dioxide per tonne
kg CO_2/GJ	kilograms of carbon dioxide per gigajoule
g CO_2/kWh	grams of carbon dioxide per kilowatt hour
g CO_2/Nm^3	grams of carbon dioxide per normal cubic metre*
g CO_2/km^3	grams of carbon dioxide per kilo (thousand) cubic metres (of industrial water)
MJ/t	megajoules per tonne
kJ/Nm^3	kilojoules per normal cubic metre (of gaseous commodity)
kJ/kWh	kilojoules per kilowatt hour
Wh/Nm^3	watt hours per normal cubic metre (of gaseous commodity)
kg CO_2/MJ	kilograms of carbon dioxide per megajoule
kg/MWh	kilograms per megawatt hour

*The unit of measure for all gaseous commodities is normal cubic metres (Nm^3). A normal cubic metre is a cubic metre of gas at standard pressure and temperature.