ENERGY USE IN THE STEEL INDUSTRY
Energy Use in the Steel Industry
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Introduction from worldsteel

The World Steel Association (worldsteel), together with members of its Technology Committee (TECO) created the ‘Energy Use in the Steel Industry’ project. The project has developed an energy intensity measurement system for the steel industry and built a comprehensive picture of energy use in steel production for 2010. The previous energy report, published in 1998, has been widely utilised by energy experts, steel companies, universities and steel-industry associations over the last decade. It has also formed the basis of many energy measurement systems during that time.

This energy report is in two parts. The first, a high-level report, identifies the sources of energy use in the industry, discusses the technologies used and what is practical for the future. It is aimed at managers, the general public, governments and universities.

The second part contains a detailed analysis of each process, the technologies used, the impact of different types and quality of raw materials, and how each of these factors affects energy intensity. The measurement system described in the report allows for this detailed analysis. It enables participants to accurately forecast the impact of technologies on each process. By understanding these impacts, iron and steel producers can make very effective use of their assets. Steel producers can also use the measurement system as a tool so they can understand the capabilities or potential of their existing processes, technologies and practices.

Global steel production reached 1,547 million metric tonnes (Mt) in 2012, up almost 2% from 1,518 Mt in 2011. Steel production will continue to grow in the next decades to meet demand. This is largely driven by developing countries with increasing populations and growing wealth.

The key economic and environmental issue for steel producers is to decrease the energy intensity of their steel production processes. In turn, this reduces the intensity of emissions per tonne of steel. The energy intensity of the steel production process has decreased by 50% over the past 40 years. This means the energy intensity of the industry is close to technical and practical minimum limits. These energy savings have required a high level of investment in: energy-efficient technologies; improving asset management and process reliability; and increasing yield in steelmaking and shaping processes. In the future, the main opportunities for energy savings will come from increased use of economically available scrap, transfer of best practices, waste heat recovery, and reducing yield losses.

This report describes the methodology used to measure the energy intensity of steelmaking processes. It also contains case studies which describe efficient practices and technologies which have already been implemented at iron and steel manufacturing sites globally.

The measurement methodology was developed by the steel-producing members of this project. It will be used in future energy intensity analyses and is available online to worldsteel members. The methodology also offers worldsteel members a very effective tool to develop improvement plans. A worldsteel reference plant has been developed based on data from existing operations. Members can measure themselves against this reference to identify which parts of their operations can be improved. It identifies the practical levels of performance that are currently being attained in the industry. All information used in this report is based on actual experience and reported data from existing, operating sites.

This report contains an overview of the current research into steelmaking processes and includes actual research results from participating companies. The report also contains information about energy efficient technologies which are still under development but are already in use. Members
of worldsteel will be able to continually follow the progress of these technologies at any time by accessing the worldsteel system.

The results of this report were presented, discussed and accepted by the Technology Committee at its meeting (TECO-03) in Chicago during May 2013.
Foreword by the Secretaries of the Energy Use Project

This report presents the final findings of the 2013 Energy Use in the Steel Industry project. The report details the energy intensity measurement methodology, processes and systems used to create the report and includes analysis, conclusions and recommendations based on the information obtained.

Energy represents one of the most important resource challenges for this century. Sources of energy and their impact on emissions to the atmosphere will only become more critical in the future.

The cost of energy accounts for 15 to 20% of the total cost of steel production depending on the region. Energy prices will continue to rise in the future as fossil fuels become more difficult to source. To counter this, steel producers must make their steelmaking and shaping processes more efficient, utilise available and efficient ironmaking technologies, and make use of alternative fuels or reduction agents for iron and steel production.

The energy intensity of steel production affects the environmental impact of the industry. When steel producers decrease their energy intensity, it has a direct and positive impact on greenhouse gas emissions. Future regulations, legislation, and emission or license limits will create additional pressure on steel producers to extract all the energy they can from any source within the steelmaking value chain. They will also need to take every possible opportunity to evaluate and implement practices or technologies which decrease energy intensity or utilise all the available energy from iron- and steelmaking processes.

Steel producers worldwide are already developing and testing new, energy efficient technologies which may decrease energy intensity. Not every technology can be implemented at every plant. Our goal was to collect information about practical, effective and available technologies which have been implemented. The level of implementation and experiences with these technologies were analysed as part of this project.

Actions taken by steel producers to decrease the energy intensity of their operations differ widely from plant-to-plant and within different countries and regions. These actions are affected by management decisions, economics, and regulations rather than technical consideration.

The main steps steel producers take to improve the energy efficiency of their processes usually reflect local variations in the importance of a number of factors. These include the cost of primary energy and electricity, raw material quality, the nature of installed technologies (and their processes and yields), product mix and demand.

We would like to thank the dedicated team who embarked on this project in 2011. They have continued to develop the material, methodology and process of the measurement system and evaluated the technologies and the many case studies provided.

As a result, worldsteel has a very valuable, permanent, online energy intensity measurement methodology and process its members can utilise to develop their facilities. They can forecast the impact of proposed technologies on a site or plant before making the investment. The report provides a valuable insight into the measurement methodology and process. Iron and steel producers who have not yet used the assessment tool are encouraged to do so.

The project team was made up of experts from within the worldsteel membership. As a result, the process and information is based on real-life practical experience and real performance data obtained from operating plants. The project team has been a tremendous resource for this report and
worldsteel is grateful for their diligence, integrity and the considerable amount of personal time they willingly provided for this project.

The outcome is already regarded as a milestone for the steel industry and the online measurement methodology and process will be the industry standard for the foreseeable future. Most of the technologies detailed in this report have been successfully implemented. However, not all of them need to be installed to obtain best-in-class levels of energy intensity.

Indeed, one of the main outcomes from this project has been to show that few effective technologies need to be installed to achieve world class energy intensity performance. It is key that the technologies are effective, and that a consistent, diligent and reliable operation is in place to ensure best-in-class results are achieved from existing assets.

The World Steel Association would like to thank everyone who participated in this project. The result is a remarkable piece of research work and provided an excellent energy intensity measurement methodology and process of which they can be truly proud.

Ladislav Horvath
Manager Technology and Environment
and World Steel Fellow

Henk Reimink
Director Safety, Technology and Environment Department
World Steel Association
1. Executive summary

Energy Use in the Steel Industry is the third energy study by the worldsteel Association (formerly the International Iron and Steel Institute (IISI) until 2008). The findings of the first and second reports on energy and the steel industry were published by IISI in 1982 and 1998.

The current project covers data for the year 2010. A detailed energy-intensity calculation methodology was developed by the project team. Data was received from 44 steelworks (21 steel companies), representing 8.8% (approximately 126 Mt) of global crude steel output in 2010. The report contains the results from the energy intensity data collection system (developed within this project) which included all steelmaking activities from raw material preparation areas (in place, on site) through to the hot rolling process. It covers internal power plants, air separation or gas producing (O₂, N₂, argon) units, and flares burning metallurgical process gases. In the future, processes beyond hot rolling can be added. However, over 85% of the energy intensity occurs in this part of the steelmaking and shaping process.

The measurement comparison and data collection system have been established as online tools and are available to any worldsteel member. Members will be able to enter data for any site or facility and analyse their own results across multiple sites. They can also compare their performance relative to reference data developed from existing sites.

The data is stored anonymously and is coded to ensure future analyses use the same plant or site IDs. The tool is located on a secure website server administered by worldsteel.

The energy calculation methodology, web-based tool and new results will be reviewed regularly by worldsteel staff to identify changes in industry performance. Members can analyse the most energy-efficient technologies and their impact before making the investment. They can also add to the extensive list of practical case studies.

This analysis will enable worldsteel to calculate the level of steel industry improvement worldwide in terms of gigajoules (GJ) of energy per tonne of specific product, or GJ per tonne of crude steel. It enables each participating member to find the gap between the performance of their site or facility and identify what practices or technologies are available to reduce the gap and by how much. The tool will enable members to quantify and justify what energy intensity benefit the improvements will provide to the plant, site and organisation.

The global energy intensity for the blast furnace/basic oxygen furnace route ranges from 15.82 GJ/tonne of cast steel to 22.82 GJ/tonne. The average is 18.68 GJ/tonne of steel cast.

For an electric arc furnace (EAF) using 100% scrap, energy intensity varies between 5.34 and 8.66 GJ/tonne of cast steel. The average is 6.74 GJ/tonne of steel cast. (Note: the energy intensity of the EAF process includes refining and casting.)

In the EAF route, it is becoming popular to utilise direct reduced iron (DRI) made with natural or shale gas. This has a significant impact on the overall process of making steel from iron ore as the combined DRI/EAF process uses more energy than a BF-BOF process. However, due to the use of natural gas to make DRI it produces less CO₂ per tonne of crude steel if combined with an EAF and charged at high temperatures, (over 500⁰C) than a BF-BOF process route.

A general summary identifying the methodology and process of the assessment system will be made public. A detailed analysis report identifying the outcome of the assessment system will only be available to participating worldsteel members.
2. Scope and aims of the Energy Project

The Energy Use in the Steel Industry project was open to all members of the worldsteel Association and regional steel associations. In total, 31 member companies and steel associations registered for the project. Project members, together with the worldsteel Association, developed the detailed scope of this project.

The project team acknowledged the quality of the 1998 report and noted the positive influence this report has had globally and within the steel industry. The 1998 report mainly describes the different energy saving technologies available and the impact these can have on the total energy performance of a steel plant. The report did not aim to prove whether or not the technologies were effective as they were limited in their application at that time.

The project team felt that the aim of the new project should not be to simply update the 1998 report. Instead, the goal was to produce an ongoing energy intensity assessment tool that:

- Enables steel producers to make a fair comparison of their own energy consumption compared to a practical reference and competitors at both the site and facility level.
- Allows steel producers to analyse the reason for the gap between their own performance, the reference and competitors at the site and facility levels.
- Enables steel producers to monitor the improvement (or deterioration) of their energy performance over time by taking into account all of the main factors that affect energy performance (such as production level or raw material selection).
- Forecasts the impact specific technologies, practices and raw materials will have on energy intensity in the future.

As well as developing the tool, the project team also wanted to review the technologies mentioned in the 1998 report. The team assessed how many of these technologies have been implemented by the companies collaborating in this project, how successful they have been at reducing energy intensity, and which technologies can be operated efficiently.

This approach focuses on the actual energy performance of steelmaking facilities and the success and impact the implemented energy reduction technologies have had at the sites of worldsteel members. The project team decided to include most steelmaking processes ranging from the management of raw material yards to the production of hot rolled products. Data from 2010 was used for the initial data collection and analysis although the system allows data to be entered for any year.

The project has resulted in the development of two products:

1. A web-based data collection tool which is available to all worldsteel members that contributed data to this report. This measurement tool will be made available online to worldsteel members in the future. Data is stored in a secure database. Participant data is coded and remains anonymous.

2. A final report that describes the comparison methodology, the approach of the technology review, results of the initial data collection, and which energy saving technologies have been adopted effectively by participating companies.

Future users of the web tool and report will be able to:

- Calculate their energy performance and compare it to the reference data at the site and facility or plant level (for example, sinter plant, or hot strip mill).
The report will provide details of technologies which can reduce energy consumption and the typical range of performance improvements that can be expected from implementing them.

By combining all of the information, the user can calculate and track the continuous improvement potential of their operations. The improvement can be tested without the need for capital investment.

2.1 Objectives of the Energy Use Project

The goals of the energy use project were to:

- Provide opportunities for steel producers to decrease the energy intensity per tonne of crude steel at their operations.
- Provide best or good practices to utilise energy sources more effectively.
- Provide best or good practices to recover energy (heat, gas, flares and by-products).
- Enable companies to develop plans to reduce energy intensity at their plants.
- Benchmark methodologies and processes so companies can compare and prioritise investments which have the biggest impact on energy efficiency.
- Identify an energy intensity survey methodology, process and boundaries using the 1998 report as a baseline.
- Identify the energy intensity rates of the iron- and steelmaking processes in terms of GJ per metric tonne of steel cast.
Scope and aims of the Energy Project

• Compare the energy intensity, differences and improvements in steel production with the results from the 1998 Energy Use in the Steel Industry Project.

The final report of this project will be provided to companies which submitted data for this project.

2.2 Final report

This final report of the Energy Use in the Steel Industry project comprises two parts. The first part is a confidential report for participating worldsteel members which contains the analysis, details of the performance of each plant by type, detailed analysis of the effectiveness of each technology, and an assessment indicating the performance of each plant compared to a reference plant.

The second part of the report is designed for a wider audience. It contains the measurement methodology (including units and definitions), and details the impact of operational practices relating to raw materials (such as iron ore, coal and scrap) on energy intensity. It also contains the top 20 good practices, identifies the less effective technologies (based on energy intensity, economic benefit or investment hurdle) presented in earlier reports, and indicates the non-cumulative effect or limitations of technologies and practices.

The report is supported by case studies of good practices, details of techniques or technologies that work in practice, and the global energy intensity levels which are used in the industry. This information is based on the earlier energy report published by IISI in 1998. The effectiveness of technologies listed in that report are evaluated in this report. The 1998 results and analysis can be found in Appendix I of this report. (The appendices are available to worldsteel members from the Extranet or on CD.)
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3. Introduction

The steel industry is one of the world’s key industries and steel use is still one of the most important indicators of a modern society or economy. With an average growth rate of 3.9%, the industry makes a significant contribution to the world economy and steel products enable the modern lifestyle we enjoy today. Steel has become essential for mankind to live.

The steel industry is the second largest global industry (after mining), producing 1,547 Mt of crude steel in 2012. This is an increase of 80% on the 851 Mt of steel produced in 2001. Average steel use per capita has increased by 43% from 150 kg in 2001 to 215 kg in 2011. Production levels are expected to nearly double again by 2050 to meet growing demand for steel around the world as populations and wealth grow in developing countries and regions.

Steel producers have made big improvements in their businesses in recent decades, particularly in the areas of safety and health, raw materials utilisation, yield improvement, and reducing the impact of the industry on the environment. While steel producers still focus on improving their performance in these areas, energy utilisation is becoming a key area for improvement, both for economic and environmental reasons.

Since the last energy report was produced by IISI in 1998, steelmakers have implemented many improvements to reduce the energy intensity of their operations. After such an interval, many producers believed it was time for the industry to examine energy use again. By identifying the techniques and practices that utilise the least energy but meet the increasing demand for steel we aim to reduce the impact of emissions from the steel industry on the environment. The project required a high level of participation from worldsteel members who have made improvements to their operations and who were willing to share their experiences within the industry. By passing on this knowledge of best practices we aim to continue to reduce energy usage by worldsteel members globally.

3.1 Project timeline and meetings

The Energy Use in the Steel Industry project has taken approximately two years from the kick-off meeting in July 2011 to the final seminar at the May 2013 worldsteel Technology Committee (TECO) meeting in Chicago.

Table 3.1: List of Energy Use project meetings

<table>
<thead>
<tr>
<th>Meeting</th>
<th>Date</th>
<th>Location</th>
<th>Host</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>July 2011</td>
<td>Anshan, China</td>
<td>Ansteel Corporation</td>
</tr>
<tr>
<td>2</td>
<td>November 2011</td>
<td>Belgium, Brussels</td>
<td>worldsteel Association</td>
</tr>
<tr>
<td>3</td>
<td>March 2012</td>
<td>Kosice, Slovakia</td>
<td>U. S. Steel Košice</td>
</tr>
<tr>
<td>4</td>
<td>July 2012</td>
<td>IJmuiden, the Netherlands</td>
<td>TATA Steel Europe</td>
</tr>
<tr>
<td>5</td>
<td>January 2013</td>
<td>Belgium, Brussels</td>
<td>worldsteel Association</td>
</tr>
<tr>
<td>6</td>
<td>March 2013</td>
<td>Belgium, Brussels</td>
<td>worldsteel Association</td>
</tr>
</tbody>
</table>

3.2 Project members

The worldsteel Association invited all steel producers and steel associations within its membership to take part in this project. The following steel producing worldsteel members took part in this project:
1,413.6 Mt of crude steel was produced in 2010

Energy use project members produced 309 Mt of crude steel in 2010

309 Mt of steel represents approximately 21.9% of total world steel production in 2010

Figure 3.1: Participating steel-producing members

The full list of project members is available in Appendix E.

Figure 3.2: Global and project-member steel production (2010)

Energy use project members steel production in 2010 was 373.3 million ton of crude steel and it represented 26.4% of the whole world steel production.

3.2.1. Confidentiality

All members of the Energy Use in the Steel Industry project reviewed and signed a confidentiality agreement. The full text of the confidentiality agreement can be found in Appendix A.
3.3 Geographical distribution of iron and steel production

Total world crude steel production in 2010 was 1,413.6 Mt. By 2012 this figure had increased to 1,547 Mt, 3.9% higher than in 2011 (1,514.1 Mt) and 9.4% higher than 2010.\textsuperscript{[1]}

Figure 3.3: World crude steel production – 2012

Three main steel production routes are utilised to produce crude steel:

1. Blast furnace–basic oxygen furnace (BF-BOF) process accounts for 69.6% of global steel production.
2. Electric arc furnace (EAF) process route accounts for 29.3% of production.
3. The open hearth furnace (OHF) process route is the least utilised, accounting for 1.1% of world steel production.

Figure 3.4 shows the distribution of world crude steel production in 2011. The biggest steel producing region was Asia, representing 64.3% of global steel production. China is the single biggest steel producing country in the world. Chinese steel production in 2011 was more than 680 Mt and represented 45% of total steel production.
Introduction

3.4 Overview of the steelmaking process

Figure 3.4: Geographical distribution of steel production – 2011

Figure 3.5: Overview of the steelmaking process
4. Process routes and energy boundaries

This section describes the main existing steelmaking process routes and emerging ironmaking technologies. The information was provided by project members or gathered from the latest technical literature available in 2013.

The energy intensity of the two main steel production routes are:

- 18 to 21 GJ/tonne of crude steel (tCS) for the BF/BOF process route*
- 4 to 6.7 GJ/tCS for the EAF process route*

*Based on the actual average energy intensity of metallurgical processes as measured in 2010.

It is predicted that the open hearth furnace (OHF) technology will be phased-out completely by the end of this decade because of economic and environmental factors. The last open hearth furnaces are operated in India, Latvia, Russia, and Ukraine.

Figure 4.1 illustrates the basic process routes for steel production. The exact process route for individual sites can vary from this figure as each has own layout and range of implemented technologies.

![Figure 4.1: Basic steel production process routes](image)

4.1 Blast furnace process

The BF/BOF process route is the most utilised crude steel production method, accounting for 69.5% of total steel production worldwide in 2010. In the BF/BOF process route, iron ore is reduced in the blast furnace together with coke, pulverised coal injections (PCI) and/or natural gas. The hot metal is then transported to the BOF steel shop where it is turned into steel. In this step, pure oxygen is injected into the hot metal to remove impurities and excess carbon. The amount of carbon that is removed depends on the grade of steel being produced.
Scrap is added as coolant and to increase throughput at this part of the process. Scrap content is typically around 8 to 12% but can be as high as 30 to 35% if scrap is more economical than iron ore reduced using coal.

4.2 Electric arc furnace/Mini mill

The second most popular steel process route is the scrap-based EAF (also known as the mini-mill process route). This process route accounts for approximately 29.2% of total world steel production. The production of steel by the EAF route utilises scrap, DRI, and hot metal or pig/granulated iron as inputs. The quantity of each can range between 0 and 100%.

The actual composition of the EAF inputs depends largely on country-specific factors such as scrap availability. In the US, the EAF process route accounts for around 60% of steel production (worldsteel - 2011) because of the high availability of scrap. China, however, relies on the BF/BOF process route to make 89.6% of its steel (worldsteel - 2011) because of the low availability of scrap and high demand for steel to develop infrastructure.

On the basis of these figures, it is difficult to compare the energy intensity of steel production in the two countries. Recognising this, the Energy Use in the Steel Industry project has developed a methodology which allows a fair comparison of each of metallurgical processes or site.

4.3 Direct reduced iron

Direct reduced iron (DRI) is a steelmaking material produced by heating iron ore (typically 65 to 70% iron content) at a temperature high enough to strip- or burn-off oxygen and carbon. Known as reduction, the process does not allow the iron to reach melting point.

DRI is also available as a compact, transportable briquette known as hot briquetted iron (HBI). DRI and HBI are primarily used by EAF producers as a scrap supplement or substitute. However, HBI is also used in the BF to increase hot metal production and to lower coke consumption. In the BOF it is used cold as a charge to supplement scrap.

Current DRI production capacity is split between two technologies:

1. Small-scale rotary kilns which use local coal and lump iron ore.
2. Large-scale shaft furnace plants using natural gas, iron oxide pellets and lump iron ore.

Global DRI production reached 74 Mt in 2012, up from 18 Mt in 1990. DRI production has grown by an impressive average annual rate of 6.5%. The main reason for this growth is the convenience of the DRI-based EAF route for steel producers in some emerging regions of the world such as India and the Middle East where producers are endeavouring to catch-up with local demand for steel and have easy access to natural gas or other forms of cheap energy.

4.3.1 DRI products

DRI includes a variety of products which are generated from the iron ore through the process of direct reduction. In a DRI plant, the iron ore is crushed and compressed at normal ambient temperature into iron oxide pellets. The name ‘direct reduction’ derives from the process whereby iron oxide pellets are passed down through a furnace with a counter-current reducing gas flow (usually a mixture of hydrogen and carbon monoxide). The pellets are heated to just below melting point of iron. The reaction between the iron ore pellets and the hot reducing gas produces pure metallic iron pellets which have a sponge-like structure (hence the alternate name for DRI – sponge iron). Carbon dioxide and water are released as by-products during the reaction.
DRI can be produced by reducing iron ore in a shaft furnace, fluidised bed furnace or another type of furnace. The typical iron content of the iron ore used as a raw material in the DRI process is around 65 to 70%. The end product of the DRI process typically contains 95 to 97% of iron, making it a high quality source of iron for the EAF process. The DRI end product can be formed into pellets or briquettes for ease of transportation.

DRI briquette products fall into two categories:
- Hot briquetted iron (HBI) which is produced at a temperature above 650 °C
- Cold briquetted iron (CBI) which is produced at a temperature below 650°C.[4]

4.3.2. DRI reduction processes

There are two basic reduction processes:
- Gas-based DRI
- Coal-based DRI

The gas-based DRI process is more widely utilised. Natural gas is the most frequently reduced gas utilised in the production of DRI.

The DRI-based EAF route has emerged as the preferred steelmaking method in the Middle East due to lower capital expenditure requirements, low energy prices, the scarcity of scrap and abundance of natural gas available at low cost. DRI production in the region has increased at an average rate of 16.6% per annum as steelmakers ramp-up their efforts to increase steelmaking capacity and meet surging demand in the region.

Total worldwide DRI production capacity was 105 Mt in 2012. India had the largest DRI capacity at 35 Mt/year. Iran has the second largest capacity at 14 Mt/year. Together the two countries accounted for almost 50% of world DRI capacity. Other major producers include Venezuela (9.8 Mt/year), Saudi Arabia (6.9 Mt/year) and Mexico (5.9 Mt/year).
### Process routes and energy boundaries

**Figure 4.3: DRI capacity 2012 (Mt/year and % share)**

#### 4.3.3. Fire hazard risk of DRI

DRI reacts with oxygen very quickly, particularly if seawater (NaCl) is present. This can occur if DRI is transported by ship, particularly during bad weather. The reaction between DRI and oxygen is exothermic, producing heat. The sponge-like structure of DRI encourages this reaction.

DRI is a pyrophoric substance, which means it can, potentially, ignite in air spontaneously. The temperature can rise to about 150 °C, the auto-oxidation temperature. When heated, DRI reacts with water and can give off hydrogen gas in a process known as catalytic dissociation. Burning DRI is detectable as it glows red. If hydrogen is present, the burning DRI glows a hazy blue colour.

To avoid oxidation and loss of heat, it is better to use DRI products directly in an EAF while they are still hot. This reduces overall energy intensity.

#### 4.4 Smelting reduction technologies

Smelting reduction usually produces hot metal from ore in two steps. The ore is partially reduced in step one, while final reduction and melting takes place in the second stage. There are a large number of developed smelting reduction technologies and many under development. This document does not cover all smelting technologies.

The best known smelt reduction technology is the Corex® process. Its main advantage is that it can operate with non-coking coal and iron ore, although in practice a small amount of coke is also required. No sinter plant or cooking is required.

More information on the Corex® process and other smelting reduction technologies can be found in section 4.8.2.1 Corex®.

#### 4.5 Ore versus scrap steelmaking

There are two main ways in which steel is produced: from iron ore, or from recycled (scrap) steel.
Iron ore-based steelmaking accounts for nearly 70% of world steel production. In this method, iron ore is reduced to iron and then converted to steel. The main raw materials are iron ore, coal, limestone and scrap steel. The main ore-based production routes are:

- Ironmaking via the blast furnace (BF) followed by steelmaking in the basic oxygen furnace (BOF)
- Ironmaking via direct reduction (DRI) followed by steelmaking in the electric arc furnace (EAF).

Scrap-based steel accounts for about 30% of global steel production. It is produced by recycling steel in an EAF or in a BOF where it replaces hot metal.

Both production routes use steel scrap as a substitute for iron ore which saves energy. Steel scrap is sorted (as best as possible) in categories according to its alloying elements. The use of scrap as a raw material does not change the properties of the end steel products as this is refined using additives to create the final grade. This means steel can be recycled infinitely without ‘downgrading’ its quality or suitability for end-use applications.

In 2012, the share of each crude steel production process was:

- 69.6% BF/BOF
- 29.3% EAF
- 1.1% OF.

On average, 40% of the steel produced worldwide uses recycled ferrous scrap in the metallurgical processes. Worldsteel is preparing a new quality standard for scrap in cooperation with its steel-producing members.

### 4.5.1. Energy intensity: BF/BOF versus EAF

Figures 4.6 and 4.8 illustrate the differences in energy intensity between the EAF and BF/BOF routes, and between EAF (100% scrap) and DRI + EAF plants.

The influence of scrap on energy intensity in the BOF process is significant and, from an energy saving perspective, very important. Iron ore steel production and scrap-based steel production are the two main production processes analysed in this energy use project.

Where scrap input to the steel production process (BOF or EAF) is lower than 50%, the process is analysed as an iron ore based steel production route. For example, an EAF plant with DRI input higher than 50% is compared to the BF/BOF production route within this energy survey.

### 4.5.1.1. Energy intensity of the BF/BOF process compared to EAF

An energy bonus of 13.25 GJ is added to each tonne of scrap used in BOF steel shop. Note: Only one quality of scrap input is defined within this Energy Use project. An iron content of 100% is assumed.

The bonus equates to the amount of energy that can be saved by using one tonne of scrap in the BF/BOF process. Scrap does not require energy for upstream processes such as iron ore mining and transportation, treatment at site, sinter production, hot metal production, and slag treatment at the BF for example.

This correction is only applied for ore-based production routes (<50% scrap) within the energy survey. The energy bonus for each tonne of scrap is the difference between the reference energy consumption for the EAF and BOF routes (see Figure 4.4).
4.5.1.2. DRI influence on the energy intensity of the EAF process

The energy intensity of the DRI process differs depending on the fuel source. The following values are used based on worldsteel data:

- Gas-based: 13.539 GJ/t of DRI (including upstream pellet energy values)
- Coal-based: 15.316 GJ/t of DRI (including recoveries).

The total energy intensity of the EAF process using 100% scrap is 6.815 GJ/t of crude steel. The energy intensity of the EAF process increases if DRI is utilised. Theoretically DRI can be substituted for scrap in the EAF at anything from 0 to 100%. Electricity consumption rises by 2.13 GJ/t for each percentage of DRI added to the EAF charge, or by 217 kWh per tonne of DRI input. The influence of DRI on electricity consumption in the EAF process is shown in Figure 4.5.
The energy intensity of the DRI EAF process compared to the 100% scrap EAF process is shown in Figure 4.6. The energy intensity of the EAF process depends on the raw materials used. The lowest direct energy intensity of the EAF process is achieved by using liquid iron or hot metal instead of scrap or DRI. The highest direct energy intensity occurs if cold DRI is used. The total energy intensity of the EAF process using 100% scrap input is defined at the worldsteel reference plant as 6.815 GJ/t of crude steel.

The total energy intensity of the EAF process with 100% DRI input can reach 23.84 GJ/t of crude steel. This includes the upstream energy consumption required to produce direct reduced iron.

![Figure 4.6: Energy intensity of the EAF process using DRI and 100% scrap](image)

**Figure 4.6: Energy intensity of the EAF process using DRI and 100% scrap**

Figure 4.7 shows the total energy intensity of five EAF plants which use DRI. Total DRI input ranges from 59% up to 84.5%. These results are in line with the theoretical calculation and results shown in Figure 4.6.
Figure 4.7: Energy intensity of the five analysed EAF plants with DRI input

Figure 4.8: Energy intensity of worldsteel reference plant (to crude steel production) for BF/BOF and EAF
worldsteel Energy Use in the Steel Industry

Table 4.1: Energy intensity of the worldsteel reference plant

<table>
<thead>
<tr>
<th>Unit Flow</th>
<th>Energy (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BOF Plant (MJ/tonne)</strong></td>
<td><strong>Scrap based EAF Plant (MJ/tonne)</strong></td>
</tr>
<tr>
<td>Hot metal kg/t</td>
<td>917.3</td>
</tr>
<tr>
<td>Scrap kg/t</td>
<td>130.4</td>
</tr>
<tr>
<td>Lump ore kg/t</td>
<td>7.5</td>
</tr>
<tr>
<td>Lime kg/t</td>
<td>45.5</td>
</tr>
<tr>
<td>Light oil l/t</td>
<td>2.3</td>
</tr>
<tr>
<td>CO gas MJ/t</td>
<td>75.2</td>
</tr>
<tr>
<td>Natural gas MJ/t</td>
<td>61.6</td>
</tr>
<tr>
<td>Electricity kWh/t</td>
<td>77.7</td>
</tr>
<tr>
<td>HP Oxygen m³N/t</td>
<td>63.4</td>
</tr>
<tr>
<td>Nitrogen m³N/t</td>
<td>52.0</td>
</tr>
<tr>
<td>Argon m³N/t</td>
<td>0.8</td>
</tr>
<tr>
<td>Crude steel kg/t</td>
<td>1,000.0</td>
</tr>
<tr>
<td>BOF Gas MJ/t</td>
<td>789.8</td>
</tr>
<tr>
<td>Heating fuels</td>
<td>137</td>
</tr>
<tr>
<td>Utilities</td>
<td>1,305</td>
</tr>
<tr>
<td>Others</td>
<td>70</td>
</tr>
<tr>
<td>Credits</td>
<td>-790</td>
</tr>
<tr>
<td>Processing Energy</td>
<td>722</td>
</tr>
<tr>
<td>Burden upstream</td>
<td>16,952</td>
</tr>
<tr>
<td>Total Energy</td>
<td>17,674</td>
</tr>
</tbody>
</table>

Figure 4.9: Main by-products by steelmaking route

[24]
On average, the production of one tonne of steel creates between 200 (EAF) and 450 kg (BF/BOF) of by-products. These include slags, dusts, sludge and other materials. The total by-product volume depends on factors such as raw materials quality, operating practices and yield.

While the amount of steel created from scrap is constantly increasing, there will always be a need to produce steel using iron-ore and coking coal to meet growing demand. Around 40% of the world’s total steel production is manufactured from scrap using electric arc furnaces and scrap additions to the conventional basic oxygen furnace processes.

Over 500 Mt of scrap was used to make the 1,300 Mt of global steel produced worldwide in 2011.

The process route a steelmaker will use depends on a number of factors such as:

- Price and availability of raw materials (mainly iron ore, coking coal, scrap)
- Production demand or capacity per year
- Product quality required
- Landfill availability or by-product sales demand/availability
- Environmental considerations
- Scrap availability.

### Table 4.2: Crude steel production by process in 2011

<table>
<thead>
<tr>
<th>Region</th>
<th>Production (Mt)</th>
<th>BF/BOF (Mt)</th>
<th>EAF (Mt)</th>
<th>OHF (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>177.2</td>
<td>56.7</td>
<td>42.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Other EU</td>
<td>37.9</td>
<td>26.8</td>
<td>73.2</td>
<td></td>
</tr>
<tr>
<td>CIS</td>
<td>113.5</td>
<td>64.2</td>
<td>20.9</td>
<td>14.9</td>
</tr>
<tr>
<td>NAFTA</td>
<td>117.5</td>
<td>39.9</td>
<td>60.1</td>
<td></td>
</tr>
<tr>
<td>Central and South America</td>
<td>49.3</td>
<td>62.3</td>
<td>36.6</td>
<td></td>
</tr>
<tr>
<td>Africa</td>
<td>15.6</td>
<td>32</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Middle East</td>
<td>20.8</td>
<td>11.1</td>
<td>88.9</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>974.9</td>
<td>79.8</td>
<td>20.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Total crude steel production</td>
<td>1514.1</td>
<td>69.5</td>
<td>29.2</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Scrap prices follow the prices of iron ore. World prices tend to be set in United States which has the largest open scrap market. Scrap prices experience seasonal changes – rising significantly in winter, while falling in spring and summer. Prices are influenced by the demand for steel and by transport costs (especially shipping).

Energy and GHG emissions intensity are significantly affected by the use of ferrous scrap. The capital cost of an EAF plant is also around one-third that of a BF/BOF process route. Using one metric tonne of steel scrap reduces CO₂ emissions by 1.54 tonnes.
4.6 Raw materials availability

World iron ore resources are estimated to be in excess of 800 billion tonnes, which translates to a potential iron content of 230 billion tonnes. Proven reserves total 180 billion tonnes, with an iron content of 87 billion tonnes.

Iron content varies greatly depending on the type of ore reserve. Between 2008 and 2011, the average iron content of iron ore at the mine decreased from 48.67 to 47.06%.[14] (The iron content of iron ore is measured before beneficiation.) The reduction of 1.6% in the iron content of ore in this period means that more energy is required to process the gangue material in the BF if it is not beneficiated.

4.6.1. Influence of raw material quality on energy intensity

Utilisation of low-grade raw materials during the production of hot metal will have a negative influence on fuel (coke, PCI) and oxygen consumption as the gangue is converted to slag and must be brought up to the melting point of iron.

If the iron content of iron ore is increased by 1%, coke consumption is typically decreased by 1.5 to 2%. From the worldsteel raw materials report[14] it is evident that the decrease in iron content of 1.6% between 2008 and 2011 increased coke consumption in the BF by 2.4 to 3.2%. This is a very simple example of how a small change in iron content can significantly influence coke consumption and CO$_2$ emissions.

Increasing the hot blast temperature by 100°C reduces coke consumption by approximately 10 kg per tonne of hot metal.

It is not difficult to improve iron ore quality to a level of 63 to 68%, an efficient level for steelmaking. Beneficiation processes such as magnetic separation and flotation can raise the iron content of ore significantly. This process is most efficient if it is completed at the mine site which avoids the need to ship unwanted material.[14]

4.6.1.1. Slag rate

When ore with a lower iron content is used, the amount of slag produced can increase from 250 to 370 kilograms of slag per tonne of hot metal (tHM). Blast furnace production can decrease from 3.0 to 1.7 tHM/m$^3$/day. For example, in China the typical slag rate ranges from 320 to 350 kg/tHM. In Europe it ranges between 250 and 270 kg/tHM. The slag rate has a big influence on the energy intensity of hot metal production.

The energy required to heat and treat the gangue material is potentially recoverable from the slag by recuperating the waste heat. However, this technology is still not fully developed and implemented within the steel industry. It takes 2.7 GJ of energy to melt each tonne of gangue.

4.6.2. Utilisation of lower grade coal in metallurgical plants

4.6.2.1. Coke rate

Coke Strength after Reaction (CSR) has an impact on the volume of coke needed. Increasing the CSR from 45% to 65% means coke consumption can decrease from 555 to 470 kg/tHM. Effectively that decreases energy intensity by 2.5 GJ/tHM.

Higher quality coke is also needed when pulverised coal (PCI) is injected into the blast furnace. This ensures adequate permeability of the coke burden and avoids the coke being crushed which may create a blockage or partial blinding layer in the burden.
4.6.2.2. Coal in the steel industry

Globally coal provides 25% of our primary energy, 40% of the electricity produced and nearly 70% of steel production via the BF/BOF process. In its most recent study, the German Federal Institute for Geosciences and Natural Resources (BGR) estimated the world’s current proven recoverable global coal reserves at 997.2 billion tonnes. This represents over 144 years of production at current levels. In contrast, proven oil and gas reserves will last around 46 to 63 years at current production levels.\cite{20}

Coal reserves are found in almost every country. Recoverable reserves are available in around 70 countries. The biggest reserves are in the China, India, Russia and the US. China’s coal reserves account for 12.6% of the world’s total.

![Figure 4.12: World coal reserves\cite{20}](image)

4.6.3. Utilisation of low quality iron ore in metallurgical plants

Global crude steel production is likely to continue to grow at a rate of around 3 to 4%/annum. The US Geological Survey estimates iron ore reserves will grow at around 7.5%/annum. The increasing rate of crude iron ore reserves occurs as some resources are converted into reserves and due to the discovery of additional resources.
As exploration increases, iron reserves are expected to rise, but they are likely to have a lower iron content. From Figure 4.13 we can predict:

- The growth rate of identified reserves is more than 7.5%.
- Iron content varies greatly depending on the type of iron ore reserve.
- Global crude steel production is likely to continue to grow at a rate of 3 to 4%.
- Based on current iron ore reserves and steel production growth figures, steel demand could easily be fulfilled uninterruptedly for the next 50 years.

Raw materials suppliers and some members of worldsteel currently increase the iron content of ore (through beneficiation) from levels as low as 25% up to 66%. The iron content of the beneficiated products is 65% on average, with maximum iron content around 68%.

The worldsteel report into raw materials showed that iron ore with high gangue content (low grade ore) can be beneficiated. If the beneficiation is done at the mine site it decreases the costs of transport and storage. It also reduces the amount of energy required to grind and mix the ore at the sinter plant, and in the sintering and blast furnace processes. Less slag is produced and the production rate of the blast furnace is increased.

The specific energy consumption of the iron ore beneficiation process ranges from 2 to 57 kWh/tonne of processed iron ore. The exact power consumption depends on factors such as the liberation characteristics of the ore, product size and downstream requirements.

### Scrap types and quality

Three types of scrap were defined in the Energy Use project:

**Internal Scrap:** Also known as closed-loop iron scrap, this category includes any scrap reused in the same process. For example, in a BF, scrap pig iron can be fed back into the BF.

**External Scrap:** Scrap sourced from outside the plant. This category can include hot metal (or pig iron) produced outside the plant where it will be used.

**Home Scrap:** Steel scrap that is utilised within the plant where it originates. This includes hot metal from the BF, pig iron produced onsite and which will be used in the BOF or EAF, and any scrap produced in processes after casting such as trimmings, head and tail cuts, and oxides recovered from reheating or pickling.
In the BOF shop the scrap rate can be varied to replace iron ore. The use of scrap decreases the need for upstream production of hot metal.

Variations in inputs and outputs are used to calculate the energy savings provided by using scrap. The calculated result is 14,150 MJ per tonne of high quality pre-consumer scrap.

For low quality end-of-life scrap, the energy saving is affected by the presence of gangue materials and oxides. This can reduce the savings to below 12,000 MJ/t.

For the Energy Use project, one main quality of scrap was defined. An energy bonus of 13.25 GJ is applied to each tonne of scrap (100% iron) used in BOF steel shop.

Higher scrap use requires other techniques such as coke charging to be documented.

4.6.4.1. Scrap boundaries

![Diagram](Image)

*Figure 4.14: Iron scrap boundaries at metallurgical plants\(^{[20]}\)*
4.7 Power plants and auxiliary plants

The main goal of power plants in metallurgical plants is to produce steam and electricity for use in all steelmaking processes. Power plants can consume most of the surplus industrial gases at a plant and can contribute to maintaining stable gas pressure in the pipeline system.

The main products of boilers (such as waste heat recovery boilers or power plant boilers) are high- and low-pressure steam. The energy efficiency of steam production has increased over the past few decades, but the typical energy efficiency of boilers are still around 30%.

4.8 Alternative ironmaking technologies

The BF/BOF has been the most widely utilised steel production process for several decades. However, factors such as global requirements for new steel products, new emission limits, and higher costs for raw materials are forcing steel producers to intensify their efforts to develop new, alternative ironmaking process routes.

The main drivers for new ironmaking technologies include the need to:

- Utilise readily available and cheaper low-quality raw materials such as inferior non-coking coals and non-agglomerated iron ores.
- Reduce the operations of coke oven and sinter plants.
- Make better use of capital and reduce operating costs.
- Reduce the production of emissions and waste materials.
- Create flexible operations.
The authors of the 1998 Energy Use report analysed actual data from 1996 to ascertain the energy intensity of alternative ironmaking technologies which were available or under development at the time.

For smelting reduction processes the CCF, Corex®, DIOS, HIs melt and Romelt technologies were analysed. At the time, only Corex® was commercially available.

In 2012 the availability of new, alternative ironmaking technologies is still very low. A lot of the technologies developed over the last decades are still not fully commercialised or results have not totally achieved the required level of throughput per unit.


An ironmaking technology study published by the US Department of Energy in 2000[^19] found that the most energy-efficient steel production process is still the EAF technology utilising 100% scrap. The report’s authors summarised the developed ironmaking technologies and those under development in terms of Capex, electricity consumption, energy use and emissions. Table 4.3 shows the list of ironmaking technologies in terms of their energy intensity.

### Table 4.3: Ironmaking technologies listed in terms of energy intensity[^19]

<table>
<thead>
<tr>
<th>Class</th>
<th>Technology Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest</td>
<td>1. 100% steel scrap</td>
</tr>
<tr>
<td></td>
<td>2. Blast Furnace - Hot metal - N.R. Coke</td>
</tr>
<tr>
<td></td>
<td>3. Blast Furnace - Hot metal - C.P. Coke</td>
</tr>
<tr>
<td></td>
<td>4. Tecnored hot metal with cogeneration</td>
</tr>
<tr>
<td></td>
<td>5. Hismelt</td>
</tr>
<tr>
<td></td>
<td>6. Mini Blast Furnace</td>
</tr>
<tr>
<td></td>
<td>7. MIDREX®/Energiron Shaft Furnace DRI (30%)</td>
</tr>
<tr>
<td>Middle</td>
<td>8. Tecnored Hot Metal without cogeneration</td>
</tr>
<tr>
<td></td>
<td>9. Cold pig iron (30%)/Scrap (70%)</td>
</tr>
<tr>
<td></td>
<td>10. Finmet</td>
</tr>
<tr>
<td></td>
<td>11. Redsmelt</td>
</tr>
<tr>
<td></td>
<td>12. Circored</td>
</tr>
<tr>
<td></td>
<td>13. Maumee Briquette RHF</td>
</tr>
<tr>
<td></td>
<td>14. HY/ENERGIRON</td>
</tr>
<tr>
<td>Highest</td>
<td>15. Circofer</td>
</tr>
<tr>
<td></td>
<td>16. ITmk3</td>
</tr>
<tr>
<td></td>
<td>17. Generic iron carbide (100%)</td>
</tr>
<tr>
<td></td>
<td>18. MIDREX® shaft Furnace DRI (100%)</td>
</tr>
<tr>
<td></td>
<td>19. Generic iron carbide (40%)</td>
</tr>
<tr>
<td></td>
<td>20. Corex®/MIDREX®</td>
</tr>
<tr>
<td></td>
<td>21. SL/RN Rotary Kiln</td>
</tr>
</tbody>
</table>

This report does not describe all of the ironmaking technologies mentioned in Table 4.3. It only covers the most developed or commercially utilised ironmaking technologies.
4.8.1. Direct reduced iron-ore technologies

The authors of the 1998 Energy Use report analysed DRI processes including: MIDREX®, SL/RN, HYL/ENERGIRON (the direct reduction technology jointly developed by Tenova HYL and Danieli), Circofer and Circored, Finmet, Iron Carbide, and Inmetco.

Direct reduction removes oxygen from iron ore without melting the iron. The MIDREX® and Energiron processes are the leading technologies for converting iron ore into highly pure DRI for use in steelmaking, ironmaking and foundry applications. These technologies typically use natural gas as a reducing agent and as fuel. However, alternative reducing sources can be used such as COG or Syngas from coal gasification.

Two major technologies have been developed to produce DRI:
1. Coal-based rotary hearth
2. Gas-based shaft reduction.

The total coal-based rotary kiln capacity installed worldwide is estimated to be about 29 Mt. About 26 Mt of this capacity is installed in India. The most typical DRI technologies are the Jindal Process, SL/RN Process, and TDR among others.

Excluding India, global DRI capacity is based predominantly on the gas-based shaft furnace technology. Natural gas DRI accounts for approximately 80% of the world’s production. Including other technologies, about 60% of all DRI is produced using MIDREX® technology.

Since 2006, when Energiron was introduced, the situation has changed. Of the plants constructed since the introduction of Energiron, around 30% utilise the MIDREX® technology. Around 38% utilise ENERGIRON. The remainder (mainly in Iran) utilise MIDREX® clone plants.

![Figure 4.16: DRI-making capacity by process](image)

Figure 4.16: DRI-making capacity by process\[^{[33]}\]
4.8.1.1. **Energiron direct reduction technology**

Tenova HYL and Danieli have formed a strategic alliance to serve the DR plant market. As part of the alliance, the two companies have combined their knowhow and technology to design and construct gas-based DRI plants. The technology is offered worldwide under the Energiron brand.

The Energiron process (see Figure 4.17) is designed to convert iron ore pellets or lumps into metallic iron using very hot (> 920°C) reducing gases which flow counter to the solid material. The conversion takes place inside a moving-bed shaft furnace operated at a pressure of about six bar. Oxygen is removed from the iron ore in reduction reactions that are based on hydrogen (H₂) and carbon monoxide (CO). The result is highly metallised DRI. Iron carbide (Fe₃C) is also formed in the reduction shaft by combining carbon with metallic iron from the reduced product.

When natural gas is used as a reducing agent, the make-up reducing gas can be produced in an external catalytic reformer (HYL III) or directly inside the reactor (Energiron Zero Reformer or ZR) by exploiting the catalytic power of the DRI and optimising the overall energy efficiency of the process. The ZR configuration is also adopted when alternative reducing gases are available such as Syngas or COG.

Given that the reformer is not in-line with the process or in the ZR configuration, it is not required. Even iron ores with relatively high concentrations of common impurities such as sulphur and phosphorous can be used without major technical limitations.

The starting point for the reduction circuit is the fresh stream of natural gas. Natural gas is mixed with recycled gas and fed into a humidifier which controls the humidity of the total stream of reducing gas in order to adjust the level of carbon deposition. The gas stream is passed through a heater where its temperature is increased above 950°C. Using an injection of oxygen, a further increase in gas temperature (to around 1,020°C) is reached at the inlet of the reactor. The spent gas is then upgraded selectively by removing both the by-products: water (simply cooling and quenching the gas) and CO₂ (using a CO₂ removal system).

The process can produce hot or cold DRI as well as HBI. When hot material is discharged from the reactor, it can be cooled in an external cooler or directly fed into the EAF using the HYTEMP system.

This process has the following advantages:

- Raw material flexibility.
- It is not sensitive to sulphur in natural gas or ore.
- No reformer is needed, leading to lower capital costs.
- High energy efficiency (87% in comparison to 70% for the most efficient DRI plants using other technologies).
- Low environmental impact with the further advantage that the CO₂, which is selectively removed can be sold for use in other industrial applications.
- Lower operating costs.
4.8.1.2. MIDREX® DRI technology

The reactor for a gas-based DRI is a shaft furnace which operates at relatively low pressure (in the range 0.4 to 1.5 bar). A shaft furnace with the largest diameter ever (7 metres) is being installed at HADEED in Saudi Arabia.

There are three main steps within MIDREX® process (see Figure 4.18):
Reduction  Pellet or lump ore is fed through a hopper at the top of the shaft furnace. The pellets, which have a typical diameter around 9 to 16 mm, are heated to between 800 and 840°C by the hot reducing gases (H₂ and CO). (As the MIDREX process has developed, the temperature has been increased and can now exceed 980°C in new plants.)

The gas flows in a counter-current to the solid material inside the furnace. The reducing gases react with the iron ore (Fe₂O₃) and convert it to metallic iron (DRI), releasing H₂O and CO₂ as by-products. The material has a residence time of around 5 to 6 hours inside the reactor.

As the spent gas leaves the reactor it is split into two streams. One stream is used as fuel (mainly for the reformer burners) while the other is compressed and mixed with natural gas before being fed into the reformer where fresh reducing gas is generated. To produce cold DRI, the reduced iron is cooled and carburised by the counter-current of gases in the lower portion of the shaft furnace. Hot DRI can also be discharged and fed into a briquetting machine to produce HBI, or fed into an EAF as hot DRI using belt conveyors.

Reforming  The MIDREX® reformer is a high-temperature, near stoichiometric CO₂ reformer. It produces a reformed gas containing about 90-92% H₂ and CO (dry bases) which is directly fed into the shaft furnace without quenching or reheating.

The reformer consists of a refractory lined chamber containing alloy tubes filled with nickel-based catalyst where the reforming reactions take place. The following reactions occur:

\[
\begin{align*}
\text{CH}_4 + \text{H}_2\text{O} &\rightleftharpoons \text{CO} + 3\text{H}_2 \\
\text{CH}_4 + \text{CO}_2 &\rightleftharpoons 2\text{CO} + 2\text{H}_2
\end{align*}
\]

The first reaction is strongly endothermic (consumes heat) while the second reaction is mildly exothermic (produces heat). The second reaction mainly occurs in the MIDREX® reformer.

Heat recovery  The thermal efficiency of the gas reformer is greatly enhanced by the heat recovery system. Heat is recovered from the reformer flue gas to preheat the feed gas mixture, the combustion air and the natural gas feed. The reformer fuel gas can also be preheated.
4.8.2. Smelting reduction processes

Corex® and FINEX are the most widely known alternative ironmaking technologies.

4.8.2.1. Corex®

Corex® is a direct smelting reduction process developed jointly by VOEST-ALPINE Industrieanlagenbau (VAI) and Deutsche VOEST-ALPINE Industrieanlagenbau. The process first appeared in 1982 and has been installed at seven installations in China, India, South Africa and South Korea. Two of the plants are in operation, while the other five are under construction.

<table>
<thead>
<tr>
<th>Country</th>
<th>Company</th>
<th>Units</th>
<th>Type</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Baosteel</td>
<td>2</td>
<td>COREX C-3000</td>
<td>1.5 Mt/year</td>
</tr>
<tr>
<td>India</td>
<td>Essar Steel</td>
<td>1</td>
<td>COREX C-2000</td>
<td>Under construction (2009)</td>
</tr>
<tr>
<td></td>
<td>JSW Steel</td>
<td>2</td>
<td>COREX C-2000</td>
<td>Under construction</td>
</tr>
<tr>
<td>South Africa</td>
<td>ArcelorMittal Saldanha</td>
<td>1</td>
<td>COREX C-2000</td>
<td>Under construction</td>
</tr>
<tr>
<td>South Korea</td>
<td>POSCO</td>
<td>1</td>
<td>COREX C-2000</td>
<td>0.8 Mt/year</td>
</tr>
</tbody>
</table>

The production capacity of the different types of Corex® plants are:

- Corex® C-1000: 600,000 t/year
- Corex® C-2000: 1,000,000 t/year
- Corex® C-3000: 1,500,000 t/year
Corex® production:\[12\]

- Hot metal production: 0.6 to 1.5 Mt/year
- Slag production: 265 to 340 kg/tHM
- Export ‘Corex’ gas production: 1,400 to 1,650 m³/tHM (in some cases 1,800 m³/tHM)
- Export ‘Corex’ gas heating value: 8 MJ/Nm³
- Electricity production: 0.8 to 1.4 MW/tHM.

The Corex® process is a two-vessel system in which the reduction of agglomerated iron ore (such as sinter, lump or pellets) and the melting and residual smelting of iron are carried out in separate vessels. This provides flexibility and enables a wider variety of coals to be used. The coal is charged to the melter-gasifier and passes through the reducing atmosphere at a temperature of 1,000°C where it is instantaneously dried and devolatilised. In these conditions, the higher hydrocarbons are cracked to form CO and H₂. No by-products such as tar, benzene or ammonia are produced.

As the gas leaves the char bed it contains 65 to 70% CO, 20 to 25% H₂ and 2 to 4% CO₂. The remainder is nitrogen. As they leave the melter-gasifier, the hot gases are mixed with cooling gas which has the same composition until it reaches 800°C. The gas is cleaned in hot gas cyclones (fines are re-circulated to the melter-gasifier) and the bulk enters the reduction shaft as the reduction gas. A small portion of the cleaned gas is diverted to the gas cooler to become cooling gas.\[6\]

The reducing gas ascends the reduction shaft counter to the descending burden. It heats and reduces the ore to produce DRI before exiting at the top of the shaft. The top gas is cleaned and cooled in a scrubber. It is then available for export as a fuel gas (dust loading <5 mg/Nm³, H₂S content 20-70 ppm).

Hot DRI, which typically achieves a metallisation of >90%, is charged continuously to the melter-gasifier where the fall velocity of the DRI is decreased in the char bed, reduction is completed and the particles are heated and melted. Hot metal and slag then drop to the bottom of the melter-gasifier and are tapped every 2.5 to 3 hours.

The export gas from the Corex® plant can be used for power generation or for the production of DRI. Power can be produced using a modern Combined Cycle Gas Turbine (CCGT) system with an estimated efficiency of up to 50%. For DRI production, the export gas must be conditioned to remove CO₂ and heated to the reduction temperature of 800°C. Depending on the plant configuration, specific DRI rates of up to 1.2 t DRI/tHM can be achieved.

The world’s first industrial scale Corex® plant is operated by ISCOR at its Pretoria Works. The plant has a nominal capacity of 1,000 tHM/day (based on lump ore) and has been operating since 1989. Average production is 315,000 tHM/year (1993-1996) which is processed (together with DRI and scrap) in the downstream EAF shop.

4.8.2.1.1. Corex® at ArcelorMittal Saldanha (South Africa)

An integrated compact mill (ICM) was started in mid-1999 at Saldanha Steel on the west coast of South Africa. The ICM is based on a Corex® C-2000 unit in combination with a Corex® gas-based DR plant,
Export gas from the Corex® plant is used for the production of DRI in an adjacent DR plant. It uses a MIDREX® shaft furnace and LINDE Vacuum Pressure Swing Absorption (VPSA) plant to remove CO₂. The DR plant is operated with a mixture of Sishen lump ore (about 65%) and CVRD pellets (35%).

Hot metal from the Corex® plant and DRI from the DR plant are both processed to make high-quality steel in a twin-shell EAF. Thin slab casting and direct rolling are used to produce high-quality hot rolled coils (HRC).

The Corex® plant at Saldanha Steel was started in December 1998 and utilises mainly local iron ores such as lump ore from Sishen mine (80 to 100%) and Companhia Vale do Rio Doce (CVRD) pellets (0 to 20%). Indigenous coal from the Van Dijksdrift and Grooteluk coal districts in South Africa is used. All of the required additives are also supplied locally.
worldsteel Energy Use in the Steel Industry

Since it was commissioned, the Corex® plant at Saldanha Steel has achieved:

- Uninterrupted production of approximately 750,000 tonnes of hot metal.
- Daily average production rate of 2,300 t (approximately 15% above the nominal capacity of the plant which represents an increase of average daily output (compared to 2003) of approximately 200 t/day).
- Plant availability (calendar utilisation) of more than 92.5%.
- A reliable supply of gas to a Corex® gas-based DR plant, yielding a production output of 700,000 tonnes of DRI.
- Longest continuous uninterrupted operation: 63 days.
- Recovery of over 95% of the Corex® slag sent to a granulation plant which is then sold to the cement industry.
- Recycling of all available mill scale, roller-hearth-furnace steel scale and DR-plant classifier sands, as Corex® burden feedstock.
- Recovery of all Corex® dust and sludge from the DR and steel plants. It is sent to a sludge granulation plant and used in the manufacture of cement.

4.8.2.1.2. Corex® at Jindal Vijayanagar Steel – Toranagallu Works (India)

Jindal Vijayanagar Steel Ltd. (JVSL) has adopted Corex® ironmaking technology in its integrated process route in India. Two Corex® C-2000 modules are in operation at JVSL.

Module-1 was commissioned in August 1999 while Module-2 was commissioned in April 2001. The process has greater operational flexibility, uses various types of non-coking coals as a primary fuel, and can utilise raw materials of lower quality.

The gas generated from the process is used to generate power which is used in the pellet plant, and as a fuel in the integrated plant complex. The special features of Corex® hot metal are its high temperature (1,480 to 1,510°C), low sulphur, low nitrogen and low levels of impurities. Finally, it is more eco-friendly compared to the conventional BF route as the sinter plant and coke ovens are not required.

Since they were commissioned, the Corex® plants at JVSL have achieved:

- Reliable, uninterrupted production output of approximately 1.6 Mt of hot metal.
- Typical plant availability (calendar utilisation) of 92.5%.
- Average fuel consumption: 1,050 kg coal/tHM.
- Average oxygen consumption: 540 Nm³/tHM.
- Reliable gas supply to power plant and as a fuel in the integrated plant complex.
- Recovery of more than 94% of the Corex® slag which is sent to slag granulation plant and used in the manufacture of cement.
- Recycling of most of the metallurgical waste such as coke fines, mill scale, iron ore fines, LD slag, limestone and dolomite fines as a Corex® burden feedstock.
- Highest plant utilisation (calendar month): 99.36% (Module-1); 95.85% in (Module-2).
- Lowest monthly fuel consumption: 945 kg/tHM (Module-1); 970 kg/tHM (Module-2).
- Lowest monthly oxygen consumption: 492 Nm³/tHM (Module-1); 510 Nm³/tHM (Module-2).
JVSL’s Corex® plants have unique operational features such as the ability to add fines directly into the melter-gasifier, the recycling of various metallurgical wastes, and a high melting rate. The JVSL plants have surpassed their rated capacity by about 15 to 20%.

With their long operational experience with Corex®, JVSL have identified a number of areas where improvements can be made to productivity, equipment availability, and the cost of reducing hot metal.[9]

4.8.2.1.3. Corex® at Baosteel Corporation – Shanghai (China)

The biggest Corex® furnaces have been built by Baosteel Corporation. The two furnaces each have a total capacity of 1.5 Mt/year. The first Corex® plant at Baosteel started production in November 2007, while the second began in March 2011.

Baosteel was the first Chinese company to install an alternative technology to the BF for the mass production of iron. A few other Chinese steel companies have shown interest in the FINEX technology developed by POSCO and Siemens VAI in South Korea.

Baosteel optimised the Corex® furnaces in 2010, and some indicators have lifted markedly since. For example, the fuel and coke ratios of the #2 furnace were improved to 919.8 kg/tHM and 144.5 kg/tHM, respectively after optimisation. Production of one tonne of iron requires 930 kg of fuels which accounts for 22% of the total cost.

A special design feature of the new Corex® module is the aerial gas distribution (AGD) system. AGD allows the injection of reduction gas through the bustle system into the Corex® shaft. Additional gas is distributed into the central zone of the reduction shaft. This enhances shaft performance as reduction occurs in a more homogeneous way. This leads to increased productivity.

Top gas from both Corex® plants is used to generate electrical energy and in heating applications throughout the Baosteel steelworks.

Since October 2010, the #1 Corex® furnace has been in stable operation with an overall availability of 94% and high productivity rates. The specific hot-metal costs and consumption figures have been at their lowest levels since the plant was started-up.

Baosteel decided to move the #1 Corex® furnace to Xinjiang Bayi Iron & Steel. The process formally started on 30 July 2012 when Bayi Steel held the opening ceremony for the local construction works. Bayi Steel is an integrated steelmaking subsidiary of Baosteel Group and is situated in the Xinjiang Autonomous Region where there is plenty of cheap iron ore and coal. Affiliated facilities and equipment are also being rebuilt at Bayi Steel.[10]

4.8.2.1.4. POSCO - Pohang Works (Republic of Korea)

The Corex® plant at POSCO’s Pohang Works was started in 1995. Situated next to the plant’s five existing blast furnaces, the Corex® plant has since produced approximately 5.7 Mt of high-quality hot metal (as of September 2004). Since May 2003 it has been operated as a FINEX process.

4.8.2.2. FINEX

FINEX is the name of an ironmaking technology developed by Siemens VAI and POSCO. Molten iron is produced directly using iron ore fines and non-coking coal rather than the traditional BF methods of sintering and reduction with coke.

Because preliminary processing is eliminated, FINEX claims its plants are less expensive to build than a BF of the same scale. Production costs can also be reduced by 10 to 15% as cheaper raw
The FINEX process is a melter-reactor. However, fluidised bed-reactors are utilised for the DRI process instead of a shaft furnace. The iron ore raw material for FINEX is a fine ore instead of lump ore. Both processes utilise non-coking coal as fuel.

In the FINEX process, fine iron ore is charged in a series of fluidised bed-reactors. As it moves downward the ore is heated and reduced to DRI using a reduction gas which is derived from the gasification of the coal. The gas flows counter to the direction of the ore.

The DRI fines compressed into hot-compacted iron and transferred to a charging bin which is positioned above the melter-gasifier. Using gravity, the iron is charged into the melter-gasifier where smelting takes place. The tapped product, liquid hot metal, is equivalent in quality to the hot metal produced in a BF or Corex® plant.

The excess gas from the FINEX process can be used for a variety of industrial applications. The low capital investment and production costs of the FINEX process are much lower than for the BF route. The environmentally friendly nature of FINEX ensures that it will be even more attractive in the future.
4.8.2.2.1. FINEX in operation

To date, two commercial-size FINEX furnaces are in operation. Both are in South Korea and were constructed by POSCO. The FINEX commercial plant was inaugurated by POSCO at its Pohang steelworks on 30 May 2007. It has a capacity of 1.5 Mt per annum.

Based on production capacity, FINEX and Corex® reactors can only replace the BF process in small- to medium-sized metallurgical companies. Their energy efficiency is still in dispute because of their high fuel consumption (almost 1,000 kg of fuel per tonne of hot metal).

4.8.3. Other alternative ironmaking technologies

While Corex and FINEX are the leading alternative ironmaking technologies, a number of other processes are being researched. These include:

- HIsarna
- HIsmelt®
- FASTMET®/FASTMELT®
- ITmk3®
- Stelco Lurgi/Republic Steel (SL/RN)
- HYLSA.

4.8.3.1. HIsarna

HIsarna is a technology which has been developed by the Ultra-Low CO₂ Steelmaking (ULCOS) consortium. ULCOS includes 48 companies and organisations from 15 European countries which have launched a cooperative research and development initiative to drastically reduce CO₂ emissions.
HIsarna is based on bath-smelting technology. Experimental equipment has been constructed at TATA Steel’s works in IJmuiden (the Netherlands). Features of the HIsarna technology include coal preheating and partial pyrolysis in a reactor, a melting cyclone for ore melting, and a smelter vessel for final ore reduction and iron production. It requires significantly less coal which reduces CO₂ emissions. It is a flexible process which allows the partial substitution of coal with biomass, natural gas or even hydrogen.[8]

The HIsarna process is a primary steelmaking process in which iron ore is processed almost directly into steel. It is based around a new type of BF called a cyclone converter furnace (CCF). The CCF makes it possible to skip the process of manufacturing pig iron pellets which is necessary in the BOF steelmaking process. Without this preparatory step, the HIsarna process is more energy efficient and has a lower carbon footprint than traditional steelmaking processes.[7]

The CCF of the HIsarna process started in 1986 and was developed in stages by Koninklijke Hoogovens/Corus IJmuiden (now part of TATA Steel). The final development stages were carried out by ULCOS in cooperation with Corus and the Rio Tinto Group. The latter contributed their HiSmelt technology to the final design of the installation. The name HIsarna comes from this process and the Celtic word for iron – ‘isarna’.

The HIsarna process is a variation of the basic oxygen steelmaking process. However, with HIsarna, the production of pig iron takes place in the CCF. The CCF shaped is like a wine bottle: a larger ‘bottle’ shape at the bottom with a thin neck at the top. The geometry of the CCF causes a hot-air cyclone to form in the neck when the furnace is heated. Crushed iron ore is injected into the cyclone together with oxygen (the oxygen is injected at the top rather than at the bottom). The heat of the cyclone causes an initial (partial) reduction reaction to take place which reduces iron ore to iron. The centrifugal force of the cyclone separates the reduced iron from its impurities and flings the reduced iron droplets against the wall of the furnace.

The molten iron droplets then drip down the furnace wall to the area where the neck widens into the bottle. Here the droplets fall into a molten iron bath in the bottom of the furnace. On the way, the droplets pass through a second set of heated oxygen injectors followed by a set of coal powder injectors.

The reduction reaction continues as normal at the bottom of the furnace. The partially reduced iron ore further reduces to regular pig iron. It separates into two molten layers: a top layer of slag and a bottom layer of molten pig iron. Both layers can be tapped individually and the pig iron can be used immediately in the basic oxygen steelmaking process.

4.8.3.1.1. HIsarna – next steps

The next stage in the current project is to test and trial the HIsarna pilot plant. The plant will allow the main technologies to be tested to determine if they can work together in operation.

A pilot plant with a capacity of 65,000 tonnes per year was first tested in 2011. Further trials were held in 2012 and 2013 to prove a longer-term operation was possible. These trials were very successful. HIsarna is now awaiting a further trial in 2014 which will be followed by an extended trial period of several months to fully test the process. New investment in a larger plant will be needed to make the HIsarna process a viable alternative to the BF/BOF process.

HIsarna will continue to be developed. In the future it is likely to be combined with a carbon capture and sequestration (CCS) process to meet the ULCOS objective of reducing CO₂ emissions.
to the atmosphere by 50%. The combination of these two technologies should see HIsarna become the first low CO₂ process to effectively influence steel production.

The IJmuiden plant will be further extended to a semi-industrial scale that will allow a capacity of 700,000 tonnes per year. This will require significant additional funding which will be addressed in ULCOS II or another funding scheme.

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**Figure 4.22: HIsarna reactor**

### 4.8.3.2. HIsmelt®

HIsmelt® differs from other ironmaking processes in that it operates on hot blast air rather than pure oxygen. In this respect it resembles a conventional BF with stoves which heat the blast to about 1,100°C. However, in the BF the volume is larger and the pressure is lower. Otherwise it is similar to other twin-vessel reduction processes with a smelting vessel and a pre-reduction/preheating fluidised bed.

Features of the HIsmelt® process include:[6]
• Low coal usage thanks to the high post-combustion ratio in the smelting vessel (up to 60%).
• Heat transfer in the smelting furnace takes place in the gas above a turbulent, foaming bath of hot metal and slag. Droplets of metal are thrown into the gas, transferring both heat and mass. HIsmelt® is the only process to use this method. It provides high post-combustion ratios.
• The high post-combustion ratio results in an off-gas with low calorific value (CV). The CV is approximately 1.5 MJ/Nm³, about half that of BF gas. Around half of the off-gas produced is used to heat the stoves, providing high preheats to both the gas and combustion air. The energy source for the preheat is the sensible heat of the off-gas (900°C), all of which is passed to the stoves as shown in Figure 4.23. Consequently, the surplus off-gas, after deducting of the stove gas and cooling, is not combustible and therefore has been discounted as a credit. This loss amounts to 3.1 GJ/tHM. It may be possible to increase the CV of the off-gas by increasing the coal rate and decreasing the post-combustion ratio.
• As blast air is used, gas volumes are high and steam recovery from sensible heat is also high – 4 GJ/tHM. However, some is used to drive the blast-air blowers, while the remainder is used in typical smelting reduction processes.

Figure 4.23: Example of a Hismelt® furnace
4.8.3.3. FASTMET® and FASTMELT® rotary hearth DRI process

FASTMET® uses a rotary hearth furnace (RHF) to convert steel mill waste, sludges and iron oxide fines to a highly metallised DRI. Carbon contained in the wastes or added as coal, charcoal or coke is used as the reductant. The iron-bearing materials, reductant and a binder are mixed and either pelletized or briquetted.

The pelletizing option uses a pan system which dries the pellets 160 to 180°C, then feeds them to the RHF. For briquetting, a roller press is used. The briquettes are fed directly to the RHF without curing or drying. As the hearth rotates, the pellets are heated to between 1,250 and 1,350°C using gas, oil or coal-fired burners. The reduction process is completed in 6 to 12 minutes.

Generally briquetting provides more flexibility to cope with the wide range of chemistry and particle sizes encountered in steel mill waste.

The main reactions for the coal-based reduction of hematite can be summarised as follows:

- Hematite to magnetite: \(3\text{Fe}_2\text{O}_3 + \text{CO} = 2\text{Fe}_3\text{O}_4 + \text{CO}_2\)
- Magnetite to wustite: \(\text{Fe}_3\text{O}_4 + \text{CO} = 3\text{FeO} + \text{CO}_2\)
- Wustite to iron: \(\text{FeO} + \text{CO} = \text{Fe} + \text{CO}_2\)
- Solution gas reaction: \(\text{CO}_2 + \text{C} = 2\text{CO}\)

The FASTMET® process can be utilised as a waste recycling plant for a steel mill. Wastes such as BF dust and sludge, BOF dust, sinter dust, EAF dust, and mill scale can be processed in a FASTMET® plant.

The benefits of the FASTMET® technology include:

- Elimination of waste disposal costs and landfill liability.
- Waste can become a quality source of iron (DRI) which can be recycled in the iron- or steelmaking processes.
- Metallisation is high – typically 85 to 92% for iron and 95 to 100% for nickel.
- Zinc contained in wastes (for example, from zinc in scrap metal) can be recovered and can be sold to zinc producers. The amount of zinc removed is 95% or higher on average.
- Three FASTMET® plants have been constructed to date:
  - Nippon Steel operates two plants, each with a capacity of 190,000 tonnes of DRI/year.
  - Kobe Steel operates one plant with a capacity of 16,000 tonnes of DRI/year.

FASTMELT® utilises the same basic process flow and equipment as FASTMET®, but includes a melter to produce hot metal. Hot DRI is discharged from the RHF and melted in an electric furnace or coal-based melter. FASTMELT® is now available commercially from MIDREX® Technologies and Kobe Steel.
4.8.3.4. ITmk3® rotary hearth DRI process

ITmk3® evolved from the FASTMET® process which was developed by MIDREX® Technologies and Kobe Steel. In the ITmk3® process, pellets are melted in the last zone of the hearth to produce a premium-quality pig iron product with a slag by-product.

The process begins with the mixing of iron ore concentrate and fine coal. The mixture is pelletized, dried and then fed into the RHF. The pellets are reduced and melted within approximately ten minutes, then discharged. The final step is the separation of iron nuggets and slag. During reduction, volatile gases produced in the reduction move into the gas space above the hearth and are combusted with air.

The heat generated, together with the heat from the burners, provides the energy required for reduction and melting. The waste gases from the RHF are fully combusted, but do contain considerable sensible heat. The waste gases first pass through a heat-recovery system to preheat combustion air. It then goes into a gas cleaning system to remove particulates before the gases are discharged to the atmosphere.

Figure 4.24: FASTMET® and FASTMELT® technology overview
For efficient performance the feed material in the ITmk3® process is typically iron ore concentrate with an iron content of 60% or higher. Silicon content should be less than 8% with coal volatiles less than 30%.

The ITmk3® technology produces nuggets. Nuggets are an ideal steelmaking feed material. They are essentially all iron and carbon, with almost no gangue and low levels of metal residuals. The nuggets are a premium quality pig iron product with superior shipping and handling characteristics. They can be shipped in bulk on inland or oceangoing vessels, railcars or trucks, and stored outside with no special precautions.

Nuggets can be handled as a bulk commodity using conventional magnets, conveyors, bucket loaders, clams, and shovels. They can be charged to an EAF, BOF, or foundry furnace in batches or continuously. In the EAF, ITmk3® nuggets provide an excellent source of low-copper feedstock.
with consistent chemical and physical characteristics. They can reduce charging time, increase melt shop productivity, and reduce energy consumption.

### 4.8.3.5. Stelco Lurgi/Republic Steel (SL/RN) – national lead DRI process

SL/RN technology is a coal-based rotary kiln reduction process. The process uses lump ore, pellets, beach iron-sands and solid carbon to produce hot or cold DRI. The process operates at high temperature (approximately 1,000°C) and near atmospheric pressure.

The reduction method uses carbon from thermal coal in the furnace. The crushed coal is mixed with a beneficiated iron source and charged to the rotary kiln. The volatile gasses from the coal create the heat and generate power in a co-generation plant.

The main raw materials in the SL/RN process are oxide pellets and/or lump ore. Some vanadium-titanium-magnetite ore (with the consistency of sand) is mixed with the coal without agglomeration and charged directly into the furnace. The waste gas is used for preheating and to start the reduction process which improves productivity. The reduction process uses brown or thermal coal as reduction agent and iron ore or iron-sand.

This process generates significant amounts of residual gas which can be used for power generation. However, coal consumption is considerably higher than for a BF. The energy efficiency of individual plants depends on the efficient use of the large amounts of residual gas. The SL/RN process is kiln-based and is the most widely used coal-based direct reduction process. The final metallisation is about 93% with carbon content around 0.1 to 0.2%. Energy consumption is lower as no coke oven or sinter plants are required for steel production.

![Figure 4.26: SL/RN technology overview][18]

### 4.8.3.6. HYLSA 4M DRI process

The HYLSA 4M process is based on a moving bed shaft furnace which reduces iron ore pellets and lump ore. It is similar to the HYL III process but without a reformer. HYSLA operates at typical reduction temperatures and intermediate reduction pressures. It does not require a reformer to generate the reducing gas as the natural gas is reformed inside the reduction reactor. The metallic
The metallic iron in the DRI acts as a catalyst for the reforming reactions. The reforming reaction occurs in parallel with the final stage of the iron ore reduction. As a result, some of the DRI reacts with the carbon and is carburised (to FeC3). Some excess free carbon is produced.

The HYLSA 4M process has the following advantages:

1. Raw material flexibility
2. Not sensitive to sulphur in natural gas or ore.
3. No reformer means lower capital costs.
4. High energy efficiency (87% in comparison to 70% for the most efficient DRI plants using alternate technologies).
5. Lower operating costs.
4.8.4. Potential impact and timeline of alternative ironmaking technologies

The potential CO₂ savings from alternative ironmaking technologies ranges from 20 to 25% compared to existing methods. If CO₂ capture and storage technologies are also installed, emissions to atmosphere can be reduced by more than 80%.

**Figure 4.27: HYLSA 4M technology overview**

**Figure 4.28: Potential impact of alternative ironmaking technologies**

<table>
<thead>
<tr>
<th>Key activities high impact</th>
<th>-30% CO₂</th>
<th>-20% alone</th>
<th>&gt; 80% CO₂ with CCS</th>
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<td>H2-Enrichment (Reforming) Course 50 POSCO</td>
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The BF is still the most utilised ironmaking technology. Over the next 20 years there is unlikely to be a technology that can operate at full scale with better economic and operational performance.

Figure 4.29 shows the theoretical development timeline for some of the most promising alternative ironmaking technologies up to 2050. As funding has been withdrawn for many projects, not all will progress at the rate shown.

![Figure 4.29: Development timeline for alternative ironmaking technologies (if adequately funded)](image-url)
5. **Project methodology and benchmarking**

The benchmarking of the energy intensity and analysed results can be divided into three different areas:

**Energy survey:** The survey analysed the energy intensity of plants and rolled-up the results to give a complete picture of sites. The plants and sites are compared during the next step of the analyses. The gap in performance between a specific plant and the reference plant is explained by the technology, performance levels and raw material quality.

**Technology survey:** This survey contains more than 190 energy saving practices and technologies. They have been analysed to identify their impact on the energy intensity of a plant.

The technology questionnaire was developed to identify the energy intensity of plants and whole sites. Each technology has the potential to decrease the energy intensity of the iron or steelmaking process, or it can increase productivity or improve the quality of the products. Project members analysed the technologies that have been implemented and identified the main drivers for their use.

**Raw materials correction:** Project members developed the correction factors used to assess the impact of raw material quality on the energy intensity of each process and the iron and steelmaking site as a whole. The main raw materials assessed included scrap, slag, pig iron, hot metal and DRI input to the BOF and EAF. Raw material quality has a large impact on energy intensity.

### 5.1 Challenge

#### 5.1.1 Reference value definitions

Determining a reference energy intensity for each process allowed the project team to develop a performance assessment for different ironmaking, steelmaking and shaping processes. This enabled the processes to be effectively compared and ranked.

The goal is to account for all inputs and outputs of each process, thereby avoiding distortions due to local conditions. This means that any input must be accounted for with a reference energy intensity that is independent of local conditions. This was achieved by setting reference values for each process. Reference values were developed by analysing a large number of operating plants which perform well. This method provided a challenging overall level of performance, but one that it is possible and practical to achieve.

Figure 5.1 shows an example analysis of a sinter plant. In order to set targets that could be reached by any plant, the project team defined the reference as that achieved by the facilities in the top 25%.
Figure 5.1: Example of an energy intensity analysis for a sinter plant

Along the value chain or production route, the calculated energy intensity of a process is compared to the reference. See Figure 5.2 for an example.

Figure 5.2: Performance assessment for multi-step production routes
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If a plant operates better than the reference, it receives a bonus (see ironmaking and coke in Figure 5.2). This covers the gap between the reference and the plant so that the product enters the following steps at the reference level.

A plant which is operating at a lower level than the reference (steelmaking in Figure 5.2) receives a penalty. The product still enters the following steps at the reference level.

Bonus and penalties are added separately across the production route with the following outcomes:

1. The net difference between the total bonus and total penalty indicates the difference between the performance of the individual plant and the reference.
2. The total penalty indicates the energy saving potential at the facility. This enables steelmakers to improve bad operations and maintain their good facilities at a level better than the reference. This also allows the impact to be seen across a whole site. Many technologies can affect downstream processes and the overall benefit may be lost on a site.

5.1.2. Energy survey

Three surveys were developed during the Energy Use project:

1. Energy survey (see section 5.1.2.1 for more information)
2. Technology survey
3. Raw materials correction factors.

The energy use survey will be open to worldsteel members continuously so they can submit data and analyse their processes. The tool will enable them to further improve energy intensity.

An expert team will check the methodology and process every year and continue to develop a more accurate energy data collection system.

The energy use project has helped to identify answers to the following questions:

- What is the average energy intensity of steel production worldwide, and for the BF/BOF and EAF process routes in particular?
- Is it possible to identify a worldsteel reference plant?
- What are the main energy efficiency techniques and technologies utilised by worldsteel members?
- What are the main drivers which influence companies to implement the most energy efficient technologies?
- What effect does raw material quality have on the energy intensity of steel production?

The energy survey was developed from the 1998 energy report and in cooperation with EUROFER ESTEP Working Group 7.

5.1.2.1. Introduction to the energy survey

The main goal of the energy survey was to determine the energy intensity of the different steel production processes. The energy intensity of each process and metallurgical plant is calculated in terms of the GJ/tonne of specific product base (such as sinter or coke), GJ/tonne of crude steel, or GJ/tonne of hot rolled coil.

A web-based tool was prepared in cooperation with a software developer to ensure the safe collection and storage of data. Each company received company- and site-specific codes which enabled them to submit data securely and anonymously.
The worldsteel data collection system was developed for use with four independent projects: Safety; Energy Intensity; CO₂ Intensity; and Maintenance and Reliability. Project members can submit data and use the systems online at any time once they are assigned access.

The energy intensity of each site is compared with that of the worldsteel reference plant. The reference levels will be re-evaluated every three to five years by energy specialists and worldsteel staff. Initial values for the worldsteel reference plant were developed from the experiences of energy-use consultants together with data collected over a five-year period from more than 60 sites around the world.

The plant will be based on an average of actual data from plants and sites with an energy performance in the top 25%. It will be known as an Achievable Reference Plant (ARP) – indicating that most worldsteel members should be able to achieve this level of performance. The ARP will provide a reference for the organisation of processes and implemented technologies.

The idea is not to determine which company or site is the best, or which plant has the best energy performance. The main purpose is to develop a methodology to monitor the energy intensity trend of plants and sites worldwide over a period of time.

The energy survey contains 15 checkpoints. Each checkpoint helps to detect data which is incorrect or not in the correct form. The web-based tool will help steel producers submit data anonymously and safely. It offers a direct reporting system and enables companies to prepare own specific comparisons or analyses of the data. Members of worldsteel can submit data for different years and analyse the energy performance trend within the company.

5.1.2.2. Energy survey checkpoints

Fifteen checkpoints were developed and implemented in the energy survey (a list and description of each can be found in Appendix F). Members can easily check if their data quality is within the predefined range. In the future, more checkpoints may be added to ensure better data collection. The checkpoints also stop incorrect or invalid data being submitted.

The energy methodology covers the main production steps from sintering and pelletizing up to the hot rolling mill. It covers both the BF/BOF and EAF process routes including the power plant, air separation unit and flares. Using the methodology developed, it is also possible to analyse the energy intensity of alternative steelmaking process routes such as smelting reduction.

5.1.2.3. Metallurgical processes covered by the energy survey

The following metallurgical processes were included in the energy survey:

- Air separation unit
- BOF
- Coking
- Continuous casting
- DRI
- EAF
- Flares
- Hot rolling mill (including mills such as hot strip, plate, ingot cogging, long products, and thin slab rolling)
- Ironmaking
- Pelletizing
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- Power plant
- Sintering
- Smelting reduction process.

5.1.2.4. Energy survey reporting system

The energy survey was developed as an Excel file which contained 13 sheets. The main data collection sheet was called the 'Physical data sheet'. The rest of the sheets were connected. Graphs and results are displayed automatically.

The results and reporting system had the following features:

- Excel graphs were implemented in the web-based tool to show results.
- Every analysed metallurgical process was compared with the worldsteel reference plant. The differences (gap) were further analysed in process waterfall graphs (see Figure 5.3 to Figure 5.13). The gap analysis can help steel producers understand the potential energy savings within their processes.
- A site waterfall graph (see Figure 5.14) was developed to show which process has the biggest influence on the energy saving potential of a site. Green bars indicate the process performs better than the worldsteel reference. Red bars indicate the process performs worse than the worldsteel reference. Steel producers should focus on these processes to reduce their energy intensity.
- The energy saving potential (ESP) of every site was calculated based on a previous analyses. It is expressed in terms of the potential terajoules (TJ) of energy which could be saved each year (see Figure 5.15).
- Process and site ranking graphs were developed within the web-based tool (see Figure 7.2 for an example).

Figure 5.3: Example of a waterfall graph for cokemaking
Figure 5.3 shows the cokemaking gap analyses. The cokemaking plant shown in this graph performs 9.6% better than the worldsteel reference. However, the consumption of electricity and other utilities (such as high and low pressure steam), coking blend and heating fuels are worse than the worldsteel cokemaking reference plant. On the other hand, this plant recovers more energy than the worldsteel reference, making it more energy efficient.

Figure 5.4: Example of a waterfall graph for the sinter process

Figure 5.5: Example of a waterfall graph for DRI
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Figure 5.6: Example of a waterfall graph for the BF process

Figure 5.7: Example of a waterfall graph for smelting reduction
Figure 5.8: Example of a waterfall graph for the BOS process

Figure 5.9: Example of a waterfall graph for the EAF process
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Figure 5.10: Example of a waterfall graph for a hot strip mill

Figure 5.11: Example of a waterfall graph for a thin slab rolling mill
Figure 5.12: Example of a waterfall graph for a plate mill

Figure 5.13: Example of a waterfall graph for a long product mill
5.1.3. Technology survey

The technology questionnaire was prepared using the 1998 IISI energy report and supplemented by available literature. Information based on the practical experience of project members was also taken...
Project methodology and benchmarking

into account. The questionnaire covers more than 190 energy efficiency techniques and technologies utilised worldwide in the steel industry.

Like the energy survey, the technology questionnaire was developed so the gap between plants and sites could be analysed. Every technique and technology has the potential to decrease the energy intensity of the steel production process, increase productivity or improve the quality of products.

Project members analysed the implemented technologies and described the main drivers behind the implementation of these technologies. As mentioned earlier, not all technologies are compatible or accumulative. It is not possible to add all of the energy savings for each technique and end-up with a total saving as some consultants claim. The information from worldsteel members is based on practical field experience.

The technology questionnaire is divided into two parts:

1. A list of techniques and technologies defined in the 1998 IISI report. This accounted for 100 of the techniques and technologies and covered all metallurgical production steps.

2. A list of other energy saving technologies identified from other reports. The 83 most energy efficient techniques and technologies were included from the available technical literature.

Both parts of the technology questionnaire were divided into eight subheadings covering the main metallurgical production steps (BF, BOS, cokemaking, DRI, EAF, hot mill, power plant and sinter plant).

Project members were asked to indicate:

• Whether the technology has been implemented in their plants
• What were the drivers behind the implementation of these technologies
• Whether the implemented technologies are delivering the expected results.

5.1.3.1. List of energy saving technologies

A complete list of energy saving technologies (EST) can be found in Appendix D. The list contains the main reasons for the implementation of the technology and the benefits these energy efficient technologies have brought.

Of the 190 listed energy efficient technologies, 24 have not been implemented at the sites of project members. This may indicate that the technology is not yet proven, or that the benefits of the technology do not cover the cost of its implementation. Each technology will be followed-up by worldsteel. If the technologies are implemented by project members in the future, a case study will be created which covers best practices and operational experience.

5.1.3.2. Results of the technology questionnaire

The time distribution of the most energy efficient techniques and technologies implementation on regions/continents level and world level, too were analysed on the base of project members answers.

The results of the technology study identified when and where the different technologies were implemented to identify the time distribution. It also indicated which technologies have been implemented (and utilised) the most for each step of the crude steel production.

The worldsteel core group concluded that the use of ESTs doesn't automatically guarantee an efficiency improvement for the entire steel production site. In many cases, EST can improve the energy intensity of processes, but can have a negative influence on the total energy intensity of the steel plant. Steel producers should analyse the effect of each EST on the site. Over-sizing and/or
incorrect application of an EST is common. Steel producers should collect as much information as possible from different sources.

The worldsteel energy intensity model allows the effect of each technology to be tested. Practical information, based on member experience, and links are established to show the impact of the technology for a site and subsequent processes. For example, if BF gas is used in a power plant it is then unavailable for the hot rolling mill reheat furnace and the site will need to purchase natural gas instead.

5.1.4. Roll-up methodology

Table 5.1 describes the method used to calculate the roll-up energy intensity of steel production. The roll-up includes the cumulative energy intensity of all processes up to the stage being analysed or, for a whole site, until hot rolling. For example, the energy intensity of the primary metal level includes the total energy input used by processes from the sinter plant, up to and including BF production.

Table 5.1: Roll-up methodology

<table>
<thead>
<tr>
<th>#1</th>
<th>Primary metal level</th>
<th>Sinter plant + Coke oven plant + ..... + Blast furnace plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>#2</td>
<td>Crude steel level</td>
<td>(#1 + Steel shop)</td>
</tr>
<tr>
<td>#3</td>
<td>Hot rolled level</td>
<td>(#2 + Hot rolling mill)</td>
</tr>
<tr>
<td>#4</td>
<td>Site level</td>
<td>(#3 + Power plant + Oxygen plant + Flares)</td>
</tr>
</tbody>
</table>

5.1.4.1 BF/BOF reference plant definitions

Reference plant values were developed based on the experiences of energy consultants and member data collected from more than 60 sites around the world over a five-year period. The energy intensity of each analysed steel facility will be compared with these values.

In the future, a new worldsteel reference plant will be established. The plant will be based on an average of actual data from plants and sites with an energy performance in the top 25%. It will be known as an Achievable Reference Plant (ARP) – indicating that most worldsteel members should be able to achieve this level of performance. The ARP will provide a reference for the organisation of processes and implemented technologies.

The public report on the energy intensity measurement methodology will not contain details of the reference plant or indicative numbers in order to avoid misinterpretation.

Table 5.2: Reference energy values (worldsteel)

<table>
<thead>
<tr>
<th>Plant</th>
<th>worldsteel reference (MJ/t)</th>
<th>Reference for impact assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar and rod mill (BOF)</td>
<td>20,585</td>
<td></td>
</tr>
<tr>
<td>Bar and rod mill (EAF)</td>
<td>9,339</td>
<td></td>
</tr>
<tr>
<td>BF</td>
<td>18,981</td>
<td>285 kg slag/t</td>
</tr>
<tr>
<td>BOF</td>
<td>17,674</td>
<td>130 kg scrap/t</td>
</tr>
<tr>
<td>Coke</td>
<td>5,719</td>
<td></td>
</tr>
<tr>
<td>CSM (BOF)</td>
<td>19,945</td>
<td></td>
</tr>
<tr>
<td>CSM (EAF)</td>
<td>8,867</td>
<td></td>
</tr>
<tr>
<td>DRI (coal)</td>
<td>15,316</td>
<td></td>
</tr>
<tr>
<td>DRI (gas)</td>
<td>13,539</td>
<td></td>
</tr>
</tbody>
</table>
Project methodology and benchmarking

Plant methodology and benchmarking

<table>
<thead>
<tr>
<th>Plant</th>
<th>worldsteel reference (MJ/t)</th>
<th>Reference for impact assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAF (100% scrap)</td>
<td>6,762</td>
<td>520 kWh/t</td>
</tr>
<tr>
<td>HRM (BOF)</td>
<td>20,365</td>
<td>UE: 18,286 MJ/t</td>
</tr>
<tr>
<td>HRM (EAF)</td>
<td>9,089</td>
<td>UE: 6,992 MJ/t</td>
</tr>
<tr>
<td>Pellet plant</td>
<td>1,700</td>
<td></td>
</tr>
<tr>
<td>Plate mill (BOF)</td>
<td>24,121</td>
<td></td>
</tr>
<tr>
<td>Plate mill (EAF)</td>
<td>12,175</td>
<td></td>
</tr>
<tr>
<td>Section mill (BOF)</td>
<td>21,183</td>
<td></td>
</tr>
<tr>
<td>Section mill (EAF)</td>
<td>9,570</td>
<td></td>
</tr>
<tr>
<td>Sinter plant</td>
<td>2,452</td>
<td></td>
</tr>
<tr>
<td>Smelting reduction</td>
<td>21,497</td>
<td></td>
</tr>
<tr>
<td>Wire rod (BOF)</td>
<td>22,209</td>
<td></td>
</tr>
<tr>
<td>Wire rod (EAF)</td>
<td>10,842</td>
<td></td>
</tr>
<tr>
<td>Average (BOF)</td>
<td>20,737</td>
<td>Shop level: 2,418 MJ/t</td>
</tr>
<tr>
<td>Average (EAF)</td>
<td>9,426</td>
<td></td>
</tr>
</tbody>
</table>

The reference values for metallurgical processes such as the coke and sinter plant can be found in Appendix B.

5.1.5. Case studies

Project members, in cooperation with worldsteel, analysed the technology questionnaire and selected 19 of the most utilised or valuable technologies from the list. Case studies were prepared for each technology. The case study authors analysed the influence the technology has on the energy intensity of steel production and its positive and/or negative influence on the environment and CO₂ intensity.

Project members divided the case studies into four groups based on their efficiency. Efficiency in this case was determined from the knowledge of project members and available information. For some technologies it is easy to determine their effect on the energy intensity of steel production. For others it is difficult, even impossible, to determine if it is effective.

Case studies were grouped into the following categories:

1. Agreed improvement from these technologies in terms of energy and/or process. (Public.)
2. Unable to determine whether the technology improved the situation/Could not achieve consensus on the level of improvement. (Public.)
3. Improvement techniques detailed in earlier reports which have not proven to be beneficial in practice. (Public.)
4. Technology not yet proven in practice or insufficient evidence exists to date. (Confidential.)

Table 5.3: List of case studies developed by project members

<table>
<thead>
<tr>
<th>Process</th>
<th>Technology</th>
<th>Group</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke Oven Battery</td>
<td>Coke Dry Quenching</td>
<td>2</td>
<td>MA Guangyu; L Horvath</td>
</tr>
<tr>
<td></td>
<td>Coal Moisture Control</td>
<td>1</td>
<td>L Horvath</td>
</tr>
<tr>
<td>Sinter Plant</td>
<td>Sinter Cooler Exhaust Gas WHR</td>
<td>1</td>
<td>MA Guangyu</td>
</tr>
<tr>
<td></td>
<td>Sinter Strand Flue Gas Recycling</td>
<td>2</td>
<td>P Wauters</td>
</tr>
</tbody>
</table>
The authors of each case study reported on the purpose, expectations and implementation drivers for each technology. Authors were also asked to describe the results before and after implementation of the specific technology.

Appendix C contains the worldsteel case study template and the final case studies.
6. Economic aspects of energy investments

Over the past 20 years the energy sector has faced a number of challenges, reflecting a new reality for the global economy. The emergence of China and India as big economic powers, significant technological advances, productivity growth, and global acceptance of ongoing development has fundamentally changed regional energy balance trends.

According to the International Energy Agency (IEA), global energy consumption is projected to rise by more than one-third between 2010 and 2035. In countries which are not members of the Organisation for Economic Cooperation and Development (OECD), energy demand is projected to grow more quickly than in member countries. The share of energy demand in non-OECD countries is expected to rise from 55% in 2010 to 65% in 2035. The strong growth in the developing world will be driven by intensive industrialisation, creation of infrastructure, higher standards of living, and the rising role of the middle class. China, where demand is forecast to rise by 60%, will be responsible for the biggest share of global energy demand and growth.

The energy supply landscape has changed significantly due to the combined effect of several factors including the development of the shale gas industry in the US, changing attitudes to the expansion of nuclear energy, and an impressive rise in subsidised renewables.

The structure of global energy supply are expected to undergo some changes over the next decade, though traditional sources of primary energy maintain their importance. Oil, gas and coals’ share of the global energy balance may decline from 81% to 75%. Gas may replace coal as the main contributor to primary energy generation. Despite the rise in use of windmills, solar power and other renewable sources, these may have a minor impact on global energy supply in the future.

Future expansion plans for nuclear power are being considered much more carefully since the Japanese tsunami and subsequent failure of the Fukushima power station. Nuclear power is likely to maintain its 12% share of the electricity mix. Hydropower is likely to remain at current levels, with minor developments or improvements to make existing sites more effective.

Regional gas markets are becoming more tightly interlinked due to the expansion in the use of liquid natural gas (LNG) and the growth in gas transportation infrastructure. Intensive development of the unconventional gas supply in Asia and the US coupled with the evolution of the LNG market, is likely to lead to diversification of gas trade and changes in the oil-linked price mechanism.

Unconventional gas production has had additional incentives over the last decade due to high gas prices and technical advances. A significant increase in the availability of shale gas has been achieved in North America. However, other regions such as Europe are hesitant because of limited public and political awareness, as well as high population densities and environmental concerns. Due to relatively cheap coal and gas, the US may have an opportunity to re-industrialise which could bring changes in the wider global manufacturing value chain. In the near future the major countries which will undertake shale gas exploration seem to be Australia, China and the US. Europe has significant opportunities in this area and shale gas may be a useful source of energy to uncouple the region’s dependency on gas from Russia.

Due to the availability of LNG exports and the increase in unconventional gas supply in the US, gas prices in Europe may continue to be suppressed. Stable demand for energy and depletion of developed gas deposits mean that Europe has been increasing its already high level of exposure to the global gas market. However, shale gas deposits in eastern Europe are vast and, as yet, unexplored.
The development of the shale gas industry has become a ‘game changer’ for the US natural gas market. The proliferation of new dry shale gas sources has increased production in the United States from 11 billion m³ in 2000 to 136 billion m³ in 2010. That equates to 23% of all dry gas production in the US. Wet shale gas reserves increased to about 1.7 trillion m³ by the end of 2009. At that time they comprised about 21% of all US natural gas reserves, the highest level since 1971.

In 2011 the US Energy Information Administration (EIA) published a study into shale gas deposits in 14 regions outside the US. Figure 6.1 shows the location of these deposits and the regions analysed. The colours indicate:

- Red: Location of assessed shale gas basins for which estimates of the ‘risked’ gas-in-place and technically recoverable resources were provided.
- Yellow: Location of shale gas basins that were reviewed, but for which estimates were not provided, mainly due to the lack of data needed to conduct the assessment.
- White: Countries which contain at least one shale gas basin considered in the report.
- Gray: No shale gas basins were considered for the report.

Although the estimates of shale gas resources will likely change over time as additional information becomes available, the report shows that existing resources are vast. An initial estimate of the technically recoverable shale gas resources in the 32 countries examined is 163.11 trillion m³.

In the US there is an estimated 24.4 trillion m³ of shale gas reserves which are technically recoverable. Adding the US total to that of the other 32 countries assessed in the EIA report puts the estimated total of shale gas resources at 187.46 trillion m³. To put this estimate in some perspective, proven world reserves of natural gas as of 1 January 2010 are about 187.1 trillion m³. Globally, the volume of technically recoverable gas is estimated at 452.95 trillion m³, largely excluding shale gas. Adding the identified shale gas resources to other gas resources increases the volume of technically recoverable gas resources by over 40% to 640 trillion m³.

Developing countries, China and India in particular, are responsible for the massive increase in coal demand between 2000 and 2010. Both will continue to use coal as a major fuel source in electricity.
generation plants. India, with low-quality steam coal, has had difficulty increasing coal production because of land use, resettlements and environmental issues.

In both countries there is a need to build a new infrastructure to supply coal to industrial areas. The demand for coal from China is likely to peak before 2025. However, demand in India will continue to rise as development appears to be slower. These trends are sensitive to infrastructure availability and the development of sources of unconventional gas.

The major challenge for coal power generation is the strengthening of global emission regulations. According to the IEA, coal (which currently has the highest growth in demand) will see its share of the electricity generation fall from 40% to about 33%.

The situation in the oil market is likely to change substantially because of the rising role of Iraq in the future. With the US able to meet all of its energy needs from shale gas, oil production and the impact of energy-efficiency measures, North America may become a net exporter of oil by 2030. This will probably impact the global oil trade with about 90% of all Middle East oil exports going to Asia by 2035 or earlier.

Electricity demand will grow globally by more than 70% by 2035. Renewables are becoming a more and more important source of energy and their share of the electricity generation mix may increase from 20% in 2010 to 31% in 2035 if subsidy levels are maintained. Electricity production from renewables in 2035 will be almost three times that of 2010 if subsidies continue. Wind energy is likely to be responsible for half the growth in renewables in OECD countries, while hydro will be the major contributor to the growth in non-OECD countries. Broadening the use of renewables will require substantial subsidies (US$3.5 billion from 2012 to 2035). Only some technologies will be able to compete with traditional sources.

Energy efficiency is a key issue for the next decades as major global industrial centres implement energy effective technologies.

World energy infrastructure will need investments of US$37 trillion in the period from 2012 to 2035, with 61% of that in non-OECD countries. According to the IEA, about 20% of the world’s population did not have access to an electricity network in 2010.

6.1 Policy limits for companies, countries or regions

6.1.1 Policies

Policies such as emission regulations, carbon taxes, tradable emission permits and other types of financial charges seek to set a price for emissions. The price reflects, to some degree, the value of the impacts and risks to the environment and human health from various types of emissions and wastes.

Taxes and other charges can also be applied to specific technologies such as inefficient vehicles or batteries. Revenues from these charges can be used to fund direct re-investment to ensure improvements in emission mitigation technologies and recycling. Industry needs to demand responsible use of carbon trading funds. If this is not done, costs could prevent businesses from investing in new technologies or mitigation techniques.

Sweden deserves attention for the impact of its policies on emissions. Emissions of carbon dioxide dropped by 8% between 1990 and 2007. Over the same period GDP grew by over 40%, largely as a result of the introduction of carbon taxes in 1990 that, among other things, changed the fuel source for district heating from oil to woody biomass.
6.1.2. Subsidies

Subsidies are applied to energy supply innovations, and the commercial development and deployment of favoured technologies for strategic or economic development reasons.

Even without help from taxes, subsidies can be effective if they are substantial and well-targeted. One of the most compelling recent examples is the ‘feed-in electricity tariff’ offered by several European countries which has rapidly increased the role of renewables such as solar power in the generation of electricity. However, many countries, such as the UK, are phasing these out already. The tariff guarantees a higher price for electricity from renewables which in turn provides stable revenue projections which help independent power producers to secure financing and adequate capital.

Subsidies must come from somewhere. If they are provided by government, they are generated through taxes elsewhere in the economy. Conversely, they may be provided as cross-subsidies from other customers or industry. In some European countries, electricity prices have increased because of these subsidies for alternative electricity producers. Consumers are locked into a limited number of providers and forced to pay for subsidies in the cost of electricity.

6.1.3. Regulations

Most countries regulate, to some degree, particulate and gas emissions from the combustion of fuels, including both fossil fuel products and biomass. Energy efficiency standards are applied in most countries to regulate appliances, buildings, vehicles and industrial equipment.

Regulations are sometimes applied in flexible ways in order to reduce the cost of compliance by allowing exchanges between those subject to the regulation. One type of market-oriented regulation is an emissions cap-and-trade policy. A cap is set, with penalties for non-compliance.

Production up to the cap may be free or allocated through auctions in the form of permits or allowances. Because these instruments are tradable, the cost provides a price signal to emitters, like an emissions tax. Each emitter has the option of reducing emissions and selling surplus allowances to other emitters. Alternatively they can maintain their emissions level and purchase the necessary allowances from someone else.

6.2 Assessment of energy technologies

The industrial sector accounted for 27% of global energy use in 2005 (IEA, 2008). The industrial sector was the second biggest energy consumer after the chemical and petrochemical industry. The global steel industry accounted for 20% of the industrial sector’s total. Total estimated energy use by the steel industry worldwide was 115 exajoules (EJ) in 2005.

The iron and steel industry traditionally includes several batch processes. The introduction of continuous casting in the 1970s and 1980s resulted in significant energy and material savings. Continuous casting now accounts for about 93% of the world’s steel production (IISI 2008). Some major energy efficiency measurements adopted by the steel industry are enhancing continuous production processes to reduce heat loss, and increase the recovery of waste energy and process gases. Efficient design of EAFs (for example, scrap preheating, high capacity furnaces and oxygen injection) can also save energy in this process.

Process modifications such as near-net shape casting and smelt reduction (which integrates ore agglomeration, cokemaking and ironmaking in a single process) offer an energy efficient alternative at the small to medium scale. They offer scope for further improvements in energy efficiency.\[28\]
6.3 Environmental protection

Metallurgical plants face a challenging period as environmental protection regulations or license limits become a major issue for steel producers worldwide.

At a local level, steel companies manage the environmental impact of their businesses. For example, they try to reduce the amount of water they use and make sure that the water that goes back into the environment is cleaner and near the same temperature as it was when removed. They also ensure that biodiversity and air quality are not compromised beyond agreed limits by the plant’s activities.

The iron and steel industry controls the emissions of many processes to within the license limits. The industry already has the technical means to meet license limits now and in the near future. Many of the materials produced as part of the steel production process (including the steel itself) are recycled, re-used or made into by-products.

Iron and steel plants typically manage emissions to:

- Air: includes emissions of dust (PM 2.5-10) and materials such as arsenic, cadmium, CO₂, lead, mercury, nickel, NOx, SO₂ and others.
- Soil: such as slag, sludge, sulphur compounds, heavy metals, oil and grease residues, salts.
- Water: includes process water with organic matter, oil, metals, suspended solids, benzene, phenol, acids, sulphides, sulphates, ammonia, cyanides, thiocyanates, thiosulphates, and fluorides (scrubber effluent) as well as returning water within a temperature limit.

6.3.1 European Union emissions trading scheme

The European Union Emissions Trading Scheme (EU-ETS) is a mandatory emissions trading system which covers all major industrial and power generation installations. Total annual emissions from these installations are capped at a maximum level. Operators must monitor and report verified emissions each year. One emission allowance (emission right) must be ‘paid’ for each tonne of CO₂ emitted.

Around 11,000 installations in 30 countries are monitored as part of the EU-ETS. The scheme initially covered 45% of EU emissions, but will increase as new sectors and gases are added from 2013 onwards.

The EU-ETS has gone through a number of phases since it was first introduced in 2005:

- Phase I: 2005 to 2007 (test period).
- Phase II: 2008 to 2012 (Kyoto period). This was the EU’s main tool to ensure compliance with its Kyoto commitments.
- Phase III: 2013 to 2020 (significant reforms). This is the main tool to ensure the EU meets its strategy to reduce emissions by 20% by 2020.

Between 2005 and 2012 free emission rights were provided to industry and electricity producers in order to maintain competitiveness. Nevertheless, electricity producers frequently increased power prices leading to windfall profits.

Industry received some free allocations based on historical emissions. Allocations were based on the expected increase in production (and therefore emissions). However, this led to over-allocation in some cases, a situation that was aggravated by the 2009 recession which reduced production in some industries by 30%.

A new free allocation calculation has been developed for industry using the following formula:
Allocation = Benchmark x Historical activity level x Correction factor x Extra allocation for added capacity,

However, electricity producers will not get free CO₂ allocations in the future.

6.3.2. Twelfth Chinese five-year plan

China is facing severe environmental impacts from rapid industrialisation, a reliance on coal as an energy source, a relatively large and energy-intensive manufacturing industry, and immature environmental protection and enforcement. The Chinese government’s twelfth Five-Year Plan (FYP-12), which covers the period 2011 to 2015, focuses on reducing pollution, increasing energy efficiency and securing a stable, reliable and clean energy supply. China’s environmental goals are likely to have far-reaching effects as they will impact and shape a range of other industrial policies in a multitude of sectors. Areas of focus in FYP-12 include:

- Energy conservation: FYP-12 contains preferential measures for developing energy-efficient technologies, as well as a mandatory reduction in energy emission intensity of approximately 17% (down from 20% in the previous FYP).

- Environmental quality: For the first time, the plan contains indicators which will hold local government officials accountable for environmental quality. Indicators include water consumption per unit of GDP and the proportion of GDP which is invested in environmental protection. FYP-12 includes a new carbon emissions intensity reduction target, especially for high-polluting and high-energy usage sectors. In order to meet that commitment, government officials have stated that a carbon tax and some type of carbon trading system may be implemented by 2016. FYP-12 also contains measures to ensure better environmental quality for cities and towns, including a ‘blue sky day’ target and other mandatory emissions limits.

- New energy: FYP-12 reflects China’s pledge to generate 15% of its energy from non-fossil fuels by 2020. This target develops previous goals set at 8.3% in 2009 and 11% by 2015. The plan includes a cap on domestic coal production, China’s largest energy source and a major contributor to the country’s environmental problems. The plan also contains significant support for the development of nuclear and hydropower, while wind power will see a threefold expansion in capacity. Domestic natural gas consumption will double over the FYP.

Figure 6.2: Estimated energy consumption in China (2010 and 2015)
6.3.2.1. Chinese national standard for energy consumption

In 2007 the Chinese government introduced a new standard which specifies the energy consumption of the main metallurgical processes (including sinter plant, BF, BOF and EAF plant). Known as GB 21256 (2007), the standard defines three levels of energy intensity for basic metallurgical processes:

- Advanced value. This value can only be reached by the most energy efficient companies.
- Access value. The average energy intensity of the top ten metallurgical companies.
- Limit value. Metallurgical plants with an energy intensity above this limit must implement energy saving technologies or find other ways to increase their energy efficiency. Plants that do not do so may be prohibited from operating in the future.

Table 6.1: Energy consumption limits for the main metallurgical processes

<table>
<thead>
<tr>
<th>Metallurgical processes</th>
<th>Limit values (kgce/t)</th>
<th>Access value (kgce/t)</th>
<th>Advanced value (kgce/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinter plant</td>
<td>≤ 65</td>
<td>≤ 60</td>
<td>≤ 55</td>
</tr>
<tr>
<td>Blast furnace plant</td>
<td>≤ 460</td>
<td>≤ 430</td>
<td>≤ 390</td>
</tr>
<tr>
<td>BOF process</td>
<td>≤ 10</td>
<td>≤ 0</td>
<td>≤ -8</td>
</tr>
<tr>
<td>EAF (carbon steel)</td>
<td>≤ 215</td>
<td>≤ 190</td>
<td>≤ 180</td>
</tr>
<tr>
<td>EAF (special steel)</td>
<td>≤ 325</td>
<td>≤ 300</td>
<td>≤ 280</td>
</tr>
</tbody>
</table>

Notes:
- Kgce/t is kilograms of coal equivalent per tonne.
- Electricity conversion factor is 0.404 kgce/kWh.
- Every 10% increase of gangue in the sinter mixture can, for example, increase sintering process energy intensity by 1.5 kgce/t sinter.
- Every 10% increase in vanadium-titanium-magnetite ore in the BF process can, for example, increase BF energy intensity by 3 kgce/tHM.

The Chinese Iron and Steel Research Institute (CISRI) are upgrading this standard. The new standard is expected to come into force from October 2014 onwards. The new standard will be stricter than the 2007 version. For example, the electricity conversion factor in the new standard will be defined as 0.1229 kgce/kWh instead 0.404 kgce/kWh, although no reason for this change was provided.
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7. General processes and techniques

This chapter was developed to describe and understand the results of the Energy Use project. It is divided into five subchapters:

1. Iron-ore based steel production (such as a coke oven or sinter plant)
2. Scrap-based steel production (EAF)
3. Hot rolling mill
4. Auxiliary facilities (such as a power plant or air separation unit)
5. Site energy intensity.

Each section contains information about the main technologies implemented in metallurgical plants, their energy inputs, and the energy intensity of each process step.

7.1 Iron-ore based steelmaking

7.1.1. Coke oven plant

Eighteen coke oven plants were analysed as part of this project. Production capacity of the plants ranged from 312,262 t/year up to 6,713,998 t/year. Average coke production capacity was 2,119,666 t/year.

7.1.1.1. Techniques and technologies applied by worldsteel members – cokemaking

Project members submitted information on energy saving technologies which have been implemented in 16 coke oven plants. Twenty energy saving technologies were identified by the project. Only two had not been implemented at the sites analysed by project members (see Figure 7.1).

The top-three energy saving technologies in use in the analysed coke oven plants are:

<table>
<thead>
<tr>
<th>#</th>
<th>Technology</th>
<th>Drivers for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Under firing gas calorific value control</td>
<td>A better cross-wall temperature is obtained, especially at the coke side. The gas utilisation ratio is also lower.</td>
</tr>
<tr>
<td>2</td>
<td>Programmed heating</td>
<td>Provides constant coke-end temperature and higher coke quality.</td>
</tr>
<tr>
<td>3</td>
<td>Steam exhausters</td>
<td>Pressure steam from the exhausters can be used downstream in the metallurgical plant.</td>
</tr>
</tbody>
</table>

The top three energy saving technologies for cokemaking are:

<table>
<thead>
<tr>
<th>#</th>
<th>Technology</th>
<th>Drivers for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coke dry quenching</td>
<td>In general, coke ovens account for 7-8% of energy consumption at a steelworks. The hot coke is normally cooled as it is taken out of the oven in a process known as coke wet quenching (CWQ). In this process, water is sprayed onto the hot coke in a quench tower. Dry quenching (CDQ) equipment has been developed to recover the waste heat from the red-hot coke by generating steam. It can be used onsite for various purposes such as electricity production or product heating. Energy savings of up to 1.7 to 1.8 GJ per tonne of dry coke are possible. This value includes a small amount (1 to 3%) of coke which is combusted in the process. For more details about this technology please see Appendix C.</td>
</tr>
</tbody>
</table>
General processes and techniques

2 Coal moisture control
This technology can save from 0.1 to 0.35 GJ of energy per tonne of dry coke. The exact saving depends on the water content of the initial coking coal. The average moisture content of the coal ranges from 9 to 12% but this depends on coal quality and weather conditions. The ideal is 5 to 6%. Water content can be reduced in a number of different ways. Reducing water content reduces the total amount of industrial gases combusted in the coke oven battery, increases productivity, and coke quality is improved. For more details about this technology see Appendix C. Note: The mentioned energy saving are only possible where the waste heat is utilised for coal moisture control.[6]

3 Programmed heating
This technology can save between 0.17 and 0.22 GJ per tonne of dry coke.

![Energy saving technologies implemented at a Coke Oven Plants](image)

Figure 7.1: Implemented energy saving technologies – coke oven plants

7.1.1.2. Average Energy Intensity and Energy Efficiency – Cokemaking

![Coke Plant (Iron ore based steel), Year:2010](image)

Figure 7.2: Energy intensity of the cokemaking process
Coke dry quenching has the biggest influence on the energy intensity of cokemaking. Four out of the five most energy efficient coke oven batteries were equipped with CDQ technology.

Altogether five coke oven batteries are equipped with CDQ and produce 0.2 to 0.56 tonne of high-pressure steam per tonne of dry coke (three produce electricity).

The energy intensity of the analysed cokemaking plants is shown in Figure 7.3. The energy intensity of the worldsteel reference coke plant is 5.719 GJ/t dry coke.

**Table 7.1: Technologies implemented at the top-five coke oven plants**

<table>
<thead>
<tr>
<th>Technology</th>
<th>PAGO001</th>
<th>QTOL001</th>
<th>PDMS002</th>
<th>JTBMO01</th>
<th>JFUH001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke Dry Quenching</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Recovery of the Sensible Heat of Coke Oven Gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovery of the Sensible Heat of Flue Gas</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Coil Moisture Control Process</td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>High-pressure Ammonia Liquor Spray Aspiration</td>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Steam Exhausters</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Electric Exhausters</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Gas Preheating</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Jumbo Coke Reactor (JCR)</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Non-recovery Coke Ovens</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMC Process Using Sensible Heat of COG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMC Process Using Steam from CDQ</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>CMC Process Direct Heating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coke Oven Gas Desulphurisation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Speed Drives (Exhauster Compressor)</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Variable Speed Drives (De-dust System)</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Coke End Temperature Control</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂ Control System in Waste Gas</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Under Firing Gas Calorific Value Control</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Programmed Heating</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of implemented technologies:</td>
<td>12</td>
<td>10</td>
<td>4</td>
<td>12</td>
<td>7</td>
</tr>
</tbody>
</table>
Figure 7.3: Energy intensity of analysed cokemaking plants

The average energy intensity of the analysed cokemaking plants is 13.29% higher than the worldsteel reference coke plant. The average energy intensity of coke plants analysed in the 1998 IISI report was 3.913 GJ/tonne of dry coke.

The best four coke oven plants (from the 2010 data) analyses have installed CDQ. Their energy intensity is between 18.9 and 54.98% lower than that of the reference coke oven plant.

7.1.1.3. Energy intensity gap analyses – cokemaking

Table 7.2: Energy intensity of worldsteel reference plant compared to Eco-tech and All-tech plants

<table>
<thead>
<tr>
<th>Unit</th>
<th>Reference</th>
<th>Eco-tech</th>
<th>All-tech</th>
<th>Conversion</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coking coal</td>
<td>kg/t</td>
<td>1,267.5</td>
<td>1,274</td>
<td>1,274</td>
<td>32.13 MJ/kg</td>
</tr>
<tr>
<td>Light oil</td>
<td>l/t</td>
<td>2.6</td>
<td>-</td>
<td>-</td>
<td>31.6 MJ/kg</td>
</tr>
<tr>
<td>CO Gas</td>
<td>MJ/t</td>
<td>489.6</td>
<td>3,200</td>
<td>2,618</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>BF Gas</td>
<td>MJ/t</td>
<td>2,224.9</td>
<td>-</td>
<td>-</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>BOF Gas</td>
<td>MJ/t</td>
<td>550.7</td>
<td>-</td>
<td>-</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh/t</td>
<td>38.3</td>
<td>31</td>
<td>31</td>
<td>9.8 MJ/kWh</td>
</tr>
<tr>
<td>HP Steam</td>
<td>kg/t</td>
<td>81.7</td>
<td>-</td>
<td>-</td>
<td>3.8 MJ/kg</td>
</tr>
<tr>
<td>LP Steam</td>
<td>kg/t</td>
<td>-</td>
<td>94</td>
<td>191</td>
<td>3.46 MJ/kg</td>
</tr>
<tr>
<td>Oxygen</td>
<td>m³N/t</td>
<td>1.1</td>
<td>-</td>
<td>-</td>
<td>6.96 MJ/m³</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>m³N/t</td>
<td>5.4</td>
<td>-</td>
<td>-</td>
<td>1.96 MJ/m³</td>
</tr>
<tr>
<td>Compressed air</td>
<td>m³N/t</td>
<td>7.3</td>
<td>-</td>
<td>-</td>
<td>1.08 MJ/m³</td>
</tr>
</tbody>
</table>
Note: Missing numbers do not indicate zero consumption. Many of these inputs (and their associated energy consumption) were not taken into account in the 1998 energy report.

The difference between the energy intensity of coke oven plants studied in the 1998 report and those studied for this report is due to the use of different calculation methodology. Authors of the 1998 report did not take into account the upstream energy and utility inputs to metallurgical processes.

The distribution rate of the coking blend input in the analysed coke plants is less than 10%. This is the same for coke compared to coke breeze production (see Figure 7.4). Seven companies did not differentiate between home coke and coke breeze production in their reports.

Figure 7.4: Coking blend compared to coke and coke breeze production

Table 7.3: Coking blend input to cookery (kg coal blend/kg coke and coke breeze) for analysed plants

<table>
<thead>
<tr>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.301</td>
<td>1.239</td>
<td>1.355</td>
</tr>
</tbody>
</table>
Figure 7.5: Coking blend input, coke production and coke breeze production (t/t dry coke)

Table 7.4: Heating fuel input to the coke production process (GJ/t of dry coke)

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.714</td>
<td>2.923</td>
<td>5.059</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7.6: Heating fuel energy input for production of one tonne of dry coke
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7.1.2. Pelletizing plant

7.1.2.1. Techniques and technologies applied by worldsteel members – pelletizing

In the pelletizing process, iron ore is crushed and ground to enable the removal of impurities by floatation or magnetic separation. The resulting beneficiated iron ore is mixed with a binding agent and then heated to create durable, marble-sized pellets. These pellets can be used in both the BF and for DRI. Pellet plants are usually located at mining sites to avoid the transportation of impurities. The non-iron bearing material can be returned to the mining site.

7.1.2.2. Average energy intensity and energy efficiency – pelletizing

Four pelletizing plants were analysed in this energy use project. The performance of the best pelletizing plant is 30.25% better than the worldsteel reference, while the worst is 17.33% below. The energy intensity of the worldsteel reference pelletizing plant is 1.7 GJ per tonne of pellets.

![Pelletising Plant (Iron ore based steel), Year:2010](image)

Figure 7.7: Energy intensity of analysed pelletizing plants

7.1.3. Direct reduced iron plant (gas- and coal-based)

7.1.3.1. Techniques and technologies applied by worldsteel members – DRI

Twenty-two energy saving technologies that can be implemented at DRI plants were analysed. Five companies reported DRI production within their sites.

The top two energy saving technologies implemented within DRI plants are:

1. Reducing fuel utilisation
2. HYL III process.

At the time of the data collection, 12 energy saving technologies were not implemented within the sites analysed.
General processes and techniques

Figure 7.8: Implemented energy saving technologies – DRI plants

Table 7.5: Technologies implemented at the top-four DRI plants

<table>
<thead>
<tr>
<th>Technology</th>
<th>BRPR001</th>
<th>RDHE003</th>
<th>RDHE005</th>
<th>QEIU110</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing Fuel (Coal, NG, Process Gas)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>MIDREX® Process</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>SL/RN Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HyL III Process</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Circoled Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circofer Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron Carbide Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inmetco Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finmet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FASTMET Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot DRI Charging</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative Fuel Used in the DRI Process</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRI Gas Utilisation (energy intensity production or steam production)</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top Flared Gas Utilisation as Fuel for the Burners</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Using Process Gas Pre-Heater</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Using Big Size Refomer Tubes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using Thin Refractory in the Shaft Furnace</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen Injection in the Bustle Zone</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using Double Port Nozzle in Bustle Zone Ring</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Increasing the Distribution Legs in Distribution Hoper</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elimination of Refomer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilisation of PSA for CO₂ Scrubbing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.1.3.2. Average energy intensity – DRI

Five DRI plants were analysed within this project. The best-performing facility is 7.95% below the reference plant value. The best performing company implemented nine energy saving technologies. The total energy intensity of the worldsteel DRI reference plant is 13.539 GJ/t using gas-based DRI production (see Table 7.6).

<table>
<thead>
<tr>
<th>Technology</th>
<th>BRPR001</th>
<th>RDHE003</th>
<th>RDHE005</th>
<th>QEIU110</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total implemented:</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 7.9: Total energy intensity of the DRI process

The direct energy intensity of the analysed DRI plants is shown in Figure 7.10. The direct energy intensity of the worldsteel DRI reference process is 11.192 GJ/t DRI. Direct energy intensity is 5.87 to 24.01% higher in the analysed plants than in the worldsteel reference DRI plant.
Table 7.6: Energy use – gas-based DRI

<table>
<thead>
<tr>
<th>Unit</th>
<th>Flow</th>
<th>Energy (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pellets kg/t</td>
<td>1,380.3</td>
<td>2,347</td>
</tr>
<tr>
<td>Natural gas MJ/t</td>
<td>10,163.6</td>
<td>10,164</td>
</tr>
<tr>
<td>Electricity kWh/t</td>
<td>92.3</td>
<td>905</td>
</tr>
<tr>
<td>HP Oxygen m³ N/t</td>
<td>17.7</td>
<td>123</td>
</tr>
<tr>
<td>LP Steam kg/t</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Screened DRI kg/t</td>
<td>984.4</td>
<td></td>
</tr>
<tr>
<td>DRI fines kg/t</td>
<td>15.6</td>
<td></td>
</tr>
</tbody>
</table>

| Natural gas          | 10,164       |
| Utilities            | 1,028        |
| Processing Energy    | 11,192       |
| Pellet Upstream      | 2,347        |
| Total energy         | 13,539       |

7.1.4. Sinter plant

Energy use project members collected information from 20 sinter plants worldwide.
7.1.4.1. Techniques and technologies applied by worldsteel members – sinter plants

Fifteen members submitted information about the energy saving technologies implemented within their sinter plants. The top four energy efficiency technologies adopted by worldsteel members are:

<table>
<thead>
<tr>
<th>#</th>
<th>Technology</th>
<th>Drivers for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Use solid waste as fuel in the sinter plant</td>
<td>Decreases coke breeze consumption.</td>
</tr>
<tr>
<td>2</td>
<td>Reduction of air leakage on wind mains</td>
<td>Construction of a side wall reduces the entry of air.</td>
</tr>
<tr>
<td>3</td>
<td>Sinter bed depth increase</td>
<td>Higher sinter production, lower solid fuel consumption.</td>
</tr>
<tr>
<td>4</td>
<td>Ignition furnace efficiency enhancement and combustion control</td>
<td>Improves combustion efficiency, decreases natural gas consumption.</td>
</tr>
</tbody>
</table>

The top three developed energy saving technologies implemented in sinter plants are:

<table>
<thead>
<tr>
<th>#</th>
<th>Technology</th>
<th>Drivers for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sinter cooler exhaust gas waste heat recovery for steam/ electricity production</td>
<td>Sintering energy consumption accounts for 15% of total energy consumption at iron and steel enterprises. This process ranks second after ironmaking. Recovering residual heat from the sintering process is one of the most effective ways to reduce energy consumption. Energy savings can range from 0.17 to 0.55 GJ/t of sinter.</td>
</tr>
<tr>
<td>2</td>
<td>Sinter strand waste-gas recycling</td>
<td>Partial recycling of sintering fumes has been commercially applied in several European and Asian plants. The technology can bring energy savings of 0.15 to 0.25 GJ/t sinter. It also offers substantial environmental benefits including lower pollutant emissions (mass per tonne of sinter) and a reduced volume of residual off-gas volume. The latter lowers the cost of applying additional end-of-pipe gas cleaning techniques. However, these techniques may negatively affect productivity and can affect sinter quality, depending on local conditions. The application of these energy saving solutions has to be assessed carefully to balance the variables and determine which is the most valuable to the organisation.</td>
</tr>
<tr>
<td>3</td>
<td>Use of solid wastes in a sinter mixture</td>
<td>Energy savings vary from 0.1 to – 0.18 GJ/tonne of sinter and depend on the carbon content of recycled metallurgical wastes in the sinter mixture (BF dust and sludge for example). This technology produces less waste giving the additional advantage that less landfill is needed.</td>
</tr>
</tbody>
</table>

Table 7.7: List of energy saving technologies implemented at top four sinter plants

<table>
<thead>
<tr>
<th>Technology</th>
<th>QWCE001</th>
<th>JTBMO01</th>
<th>QRDT003</th>
<th>PAGO001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinter cooler exhaust gas WHR - for combustion air preheating</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinter cooler exhaust gas WHR - for steam generation</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Material segregation charging</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Ignition furnace efficiency enhancement and combustion control</td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Sinter bed depth increase</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Variable speed drive control of induced draft fans</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Steam generation from flue gas recovery</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Steam generation from flue gas recovery has not been implemented by members of the Energy Use project.

Figure 7.11: Implemented energy saving technologies – sinter plant
7.1.4.2. Average energy intensity of the sinter process

Figure 7.12: Energy efficiency performance – sinter plants

The average energy intensity of the analysed sinter plants is 14.262% higher than the worldsteel reference plant. The energy intensity of the worldsteel reference plant is 2.452 GJ/tonne of sinter. The energy intensity of a sinter plant highly depends on the total amount of sinter which is returned to the sinter process as fines. If the screening process is effective, the energy intensity will be lower in the sinter plant and blast furnace (as high-quality sinter will be loaded into the BF).

Table 7.8: Energy intensity of worldsteel reference plant compared to Eco-tech and All-tech sinter plants

<table>
<thead>
<tr>
<th>Unit</th>
<th>Reference</th>
<th>Eco-tech</th>
<th>All-tech</th>
<th>Conversion</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coke kg/t</td>
<td>27.22</td>
<td>46</td>
<td>36.5</td>
<td>29.43</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>Anthracite kg/t</td>
<td>28.24</td>
<td>-</td>
<td>-</td>
<td>28.61</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>BF gas dust kg/t</td>
<td>8.22</td>
<td>-</td>
<td>-</td>
<td>14.78</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>Iron ore kg/t</td>
<td>1167.45</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>Limestone kg/t</td>
<td>151.31</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>Lime kg/t</td>
<td>3.65</td>
<td>-</td>
<td>-</td>
<td>4.05</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>Fuel MJ/t</td>
<td>49.28</td>
<td>49</td>
<td>17</td>
<td>9.8</td>
<td>MJ/kWh</td>
</tr>
<tr>
<td>Electricity kWh/t</td>
<td>49.55</td>
<td>30</td>
<td>27</td>
<td>9.8</td>
<td>MJ/kWh</td>
</tr>
<tr>
<td>LP Steam kg/t</td>
<td>2.34</td>
<td>-</td>
<td>-</td>
<td>3.46</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>Compressed air m³N/t</td>
<td>7.24</td>
<td>-</td>
<td>-</td>
<td>1.078</td>
<td>MJ/m³N</td>
</tr>
<tr>
<td>Coke upstream MJ/t</td>
<td>156.00</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>MJ/MJ</td>
</tr>
<tr>
<td><strong>Outputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Merchant sinter kg/t</td>
<td>1165.86</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>Bell sinter kg/t</td>
<td>1000</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>LP steam kg/t</td>
<td>-</td>
<td>52</td>
<td>55</td>
<td>3.46</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>Energy intensity MJ/t</td>
<td>2,452</td>
<td>1,877</td>
<td>1,546</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Note: Missing numbers do not indicate zero consumption. Many of these inputs (and their associated energy consumption) were not taken into account in the 1998 energy report.

The energy intensity of the worldsteel reference plant is higher compared to Eco-tech and All-tech plants because a different calculation methodology is used. The difference occurs because:

- Energy intensity for the worldsteel reference sinter plant also includes upstream coke production (0.156 GJ/tonne)
- BF gas dust and lime energy content is also included in this report and methodology
- No heat recovery is assumed at the worldsteel reference sinter plant in this report.

![Sinter Plant (Iron ore based steel), Year:2010](image)

Figure 7.13: Energy intensity of analysed sinter plants compared to the worldsteel reference sinter plant

![Sinter plant (Direct) Energy intensity](image)

Figure 7.14: Direct energy intensity of the analysed sinter plants compared to the reference plant
worldsteel Energy Use in the Steel Industry

The direct energy intensity of the analysed sinter plants is shown in Figure 7.14. The direct energy intensity of the worldsteel reference sinter plant is 2.281 GJ/t sinter. The total energy intensity of the new worldsteel reference sinter plant is 2.452 GJ/t sinter.

Solid fuel, as coal, input to the sinter mixture ranges from 0.032 to 0.090 t/tonne of sinter. The average solid fuel rate is 0.061 t/tonne of sinter (see Figure 7.15).

![Total solid fuel input to the Sintering process](image)

Figure 7.15: Input of solid fuel to the sinter mixture

The average fuel input (gas) to the burning head of the sinter belt is 0.119 GJ/tonne of sinter.

Table 7.9: Gas fuel input to the sinter process (GJ/t of sinter)

<table>
<thead>
<tr>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.119</td>
<td>0.03</td>
<td>0.373</td>
</tr>
</tbody>
</table>

![Gas fuels input to the sintering process](image)

Figure 7.16: Gas fuel input to the sintering process

Of the 18 sinter plants analysed, only one company produces steam at the sinter plant. The average production of low-pressure steam at this site is 42 kg/tonne of sinter.
7.1.4.3. Energy intensity trend – sintering

The average primary energy intensity of the analysed sinter plants in the 1998 report was 1.81 GJ/t of graded sinter.[6]

The difference between the energy intensity of sinter plants studied in 2010 is higher (0.6 GJ/tonne of sinter) than in 1998. Not all of the energy inputs to the sinter process were considered in the 1998 report.

7.1.5. Blast furnace plant

Data was collected from 22 BF plants around the world. The volume of hot metal produced by these plants range between 931,658 and 15,265,619 tHM/year.

Sixteen BF plants provided information about the energy saving technologies they have implemented (see Figure 7.18).

The top four energy efficient BF technologies adopted by worldsteel members are:

<table>
<thead>
<tr>
<th>#</th>
<th>Technology</th>
<th>Drivers for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>O₂ enrichment of cold blast</td>
<td>Higher pulverized coal injection (PCI) rate reduces coke consumption and the energy intensity of hot metal production.</td>
</tr>
<tr>
<td>2</td>
<td>Computer-aided control (blast stoves)</td>
<td>Provides better monitoring and control of the combustion process, improves energy efficiency. Heat demand software can be installed to provide better control and energy savings.</td>
</tr>
<tr>
<td>3</td>
<td>BF top charge distribution control</td>
<td>Reduces coke consumption.</td>
</tr>
<tr>
<td>4</td>
<td>BF injectants (tar, NG, PCI)</td>
<td>Reduces coke consumption, saves energy (coke rate), provides better raceway (heat level) control and increases BF productivity.</td>
</tr>
</tbody>
</table>

The four technologies which can save the most energy at the BF plant are:
# Technology Drivers for Implementation

## 1 BF gas recovery

The gas exported from the BF is typically used to fire hot stoves and coke batteries. Any excess gas is sent to the power plant or combined heat and power (CHP) plant. The net efficiency of the system is largely determined by how efficiently the gas is used. Gas turbines, modern high pressure steam cycle plants or Combined Heat and Power (CHP) plants are more efficient than many of the power plants currently in use at steelworks.

## 2 Pulverized coal injection to BF

PCI lowers the amount of coke required in the blast furnace, reducing the amount of energy required to produce coke. Apart from being ground to a homogeneous size, standard thermal coal can be used for PCI without additional treatment. The energy savings depend on the total amount of alternative fuel injected into the BF, but range from 0.5 to 1.4 GJ/tHM. PCI provides both an economic and energy benefit and is universally practised. Improved injection systems and distribution control can result in further savings.

## 3 Top recovery turbine

A large amount (approximately 1,700 to 2,700 m³/tHM) of BF gas is produced during hot metal production. Typical gas temperature at the outlet of the BF is 150°C, while pressure ranges from 0.155 to 0.250 MPa depending on the size of the BF. In the past, energy from BF gas was wasted as the pressure was reduced too far at septum valves. Adding a top recovery turbine (TRT) is the best way to recover the thermal energy and pressure of BF gas. The turbine is directly connected to a generator which creates electric power. A TRT unit could cover about 20% of the electricity needs of a BF. A TRT can produce between 40 and 60 kWh/tHM if dry BF gas cleaning has been implemented. If wet BF gas cleaning is used, the TRT can produced between 30 and 45 kWh/tHM.

## 4 Waste heat recovery from molten BF slag

Heat recovery from slag (that is, dry slag granulation) is being developed. Slag contains about 2 GJ/t slag of sensible heat at 1500°C. This high-grade heat allows the production of high pressure steam. Dry slag granulation has the potential to recover about 60% of this heat. This equates to 330 MJ/tHM for a furnace with a slag rate of 280 kg/tHM. This represents about 2% of the total energy input to the BF, a substantial amount considering the scale of production.

### 7.1.5.1. Applied techniques and technologies – BF plants

![Implemented energy saving technologies – BF plant](image)

Figure 7.18: Implemented energy saving technologies – BF plant
### Table 7.10: List of energy saving technologies implemented at the four most energy efficient BF plants

<table>
<thead>
<tr>
<th>Technology</th>
<th>QWCE001</th>
<th>JTBMO01</th>
<th>QRDT003</th>
<th>PAG0001</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHR from waste gas (blast stoves, preheat combustion air)</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHR from waste gas (blast stoves, preheat fuel)</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₂ enrichment of combustion air (blast stoves)</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold blast main insulation (blast stoves)</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer-aided control (blast stoves)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Electric blowers</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam blowers</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Combined (electric/steam) blowers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF injectants (tar, NG, PCI, plastic, other)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Heat recovery from slag</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of slag for cement</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Top-gas recovery turbines (TRT)</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>BF gas recovery</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Preheat of gas and air (blast stoves)</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Staggered parallel stove operation</td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Oxygen enrichment of cold blast</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Hot blast stove automation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>BF charge distribution control</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>CO₂ capture and BOS gas injection to BF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry de-dusting of BF gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total implemented:</strong></td>
<td>13</td>
<td>10</td>
<td>13</td>
<td>9</td>
</tr>
</tbody>
</table>

Note: Site JEVS003 was listed in the top five most energy efficient BF plants. However, the company did not submit information about the technologies they have implemented.
7.1.5.2. Average energy intensity and energy efficiency – BF process

![Direct energy intensity of BF process](image)

**Figure 7.19: Direct energy intensity – BF process**

The direct energy intensity of the analysed blast furnaces is shown in Figure 7.19.

![Total energy intensity (direct and upstream) of analysed blast furnaces](image)

**Figure 7.20: Total energy intensity (direct and upstream) of analysed blast furnaces**
Figure 7.21: Energy efficiency performance – BF process

The average energy intensity of the blast furnaces studied does not include the RZLD101 plant. The company uses an alternative fuel in their blast furnace which increases the energy intensity of hot metal production. For this reason it is difficult to compare their energy intensity with that of conventional blast furnaces.

7.1.5.3. Energy intensity gap analyses – BF plants

The average energy intensity of hot metal production at the BF studied is 8.72% higher than the worldsteel reference BF plant value. The energy intensity of the reference BF is 18.281 GJ/tHM. This figure includes upstream energy for coke production (1.859 GJ/t coke) and the total burden (3.507 GJ/t).

The energy intensity of the Eco-tech and All-tech plants defined in the 1998 report was 12.332 and 12.228 GJ/tHM respectively.
Table 7.11: Energy intensity of worldsteel reference BF plant compared to Eco-tech and All-tech plants

<table>
<thead>
<tr>
<th>Unit</th>
<th>Reference</th>
<th>Eco-tech</th>
<th>All-tech</th>
<th>Conversion</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bell sinter</td>
<td>kg/t</td>
<td>1,314</td>
<td>-</td>
<td>-</td>
<td>2,452 MJ/kg</td>
</tr>
<tr>
<td>Pellets</td>
<td>kg/t</td>
<td>169.2</td>
<td>-</td>
<td>-</td>
<td>1,700 MJ/kg</td>
</tr>
<tr>
<td>Lump ore</td>
<td>kg/t</td>
<td>117</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Coke</td>
<td>kg/t</td>
<td>324.9</td>
<td>361</td>
<td>297</td>
<td>30.1 MJ/kg</td>
</tr>
<tr>
<td>Coal</td>
<td>kg/t</td>
<td>163.4</td>
<td>82.2</td>
<td>200</td>
<td>31.1 MJ/kg</td>
</tr>
<tr>
<td>CO Gas</td>
<td>MJ/t</td>
<td>220.5</td>
<td>-</td>
<td>-</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>BF Gas</td>
<td>MJ/t</td>
<td>1,622.1</td>
<td>-</td>
<td>-</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>Natural gas</td>
<td>MJ/t</td>
<td>7.8</td>
<td>-</td>
<td>-</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>Fuel</td>
<td>MJ/t</td>
<td>-</td>
<td>2,854</td>
<td>-</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh/t</td>
<td>97.2</td>
<td>60.6</td>
<td>58.5</td>
<td>9.8 MJ/kWh</td>
</tr>
<tr>
<td>HP Oxygen</td>
<td>m³N/t</td>
<td>0.2</td>
<td>35</td>
<td>50</td>
<td>6.96 MJ/kg</td>
</tr>
<tr>
<td>LP Oxygen</td>
<td>m³N/t</td>
<td>34</td>
<td>-</td>
<td>-</td>
<td>4.9 MJ/kg</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>m³N/t</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>1.96 MJ/m³</td>
</tr>
<tr>
<td>Compressed air</td>
<td>m³N/t</td>
<td>22.9</td>
<td>-</td>
<td>-</td>
<td>1.08 MJ/m³</td>
</tr>
<tr>
<td>HP Steam</td>
<td>kg/t</td>
<td>-</td>
<td>122</td>
<td>114</td>
<td>3.8 MJ/kg</td>
</tr>
<tr>
<td>Hot metal</td>
<td>kg/t</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>BF Gas</td>
<td>MJ/t</td>
<td>4,608.7</td>
<td>4,700</td>
<td>5000</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>BF Dust</td>
<td>kg/t</td>
<td>7.5</td>
<td>-</td>
<td>-</td>
<td>15 MJ/kg</td>
</tr>
<tr>
<td>BF Sludge</td>
<td>MJ/t</td>
<td>8.3</td>
<td>-</td>
<td>-</td>
<td>15 MJ/kg</td>
</tr>
<tr>
<td>BF Slag</td>
<td>kg/t</td>
<td>285.9</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh/t</td>
<td>17.1</td>
<td>35</td>
<td>50</td>
<td>9.8 MJ/kWh</td>
</tr>
<tr>
<td>Energy intensity</td>
<td>MJ/t</td>
<td>18,281</td>
<td>12,332</td>
<td>12,228</td>
<td></td>
</tr>
</tbody>
</table>

Note: Missing numbers do not indicate zero consumption. Many of these inputs (and their associated energy consumption) were not taken into account in the 1998 energy report. The Eco-tech and All tech options are not usable in all cases and have therefore not been adopted. The reference is the most practical application currently available.

The blast furnace is a very flexible process and utilises a wide range of fuel sources and raw materials of different qualities. These factors impact:

- Productivity of the BF
- Fuel consumption (coal, coke, gases)
- Overall efficiency of the BF
- Total slag production
- BF gas production
- Operational mode.

BF gas production ranges from 4.314 to 7.16 GJ/tHM. Top gas production depends on factors such as the quality of raw materials, operational mode of the BF, PCI injection rate, whether air enrichment by oxygen is in place, and the temperature of the hot blast.
General processes and techniques

Figure 7.22: Gas production/tonne of hot metal (GJ/tHM)

Table 7.12: Coke consumption at the analysed BF plants (t of coke/t of HM)

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.411</td>
<td>0.339</td>
<td>0.549</td>
</tr>
</tbody>
</table>

Figure 7.23: Main solid fuel used as input to the blast furnace (coke and pulverized coal)
Figure 7.24: Total gas energy input to the blast furnace

Figure 7.25: Total electricity consumption and production – BF plant
Figure 7.26: Top gas generation compared to equivalent coke rate input to BF

7.1.6. BOF steelmaking

The BOF process is the only steelmaking process which can generate energy. This means it has an energy intensity lower than zero. The injection of pure oxygen into the BOF creates an exothermic reaction which is controlled by adding scrap which melts and thereby cools the liquid steel. The energy recovered from this process is very high and can be as much as 0.234 GJ/t of crude steel.

7.1.6.1. Applied techniques and technologies – BOF

Twenty-three energy saving technologies were identified in the BOF process. Seventeen sites submitted information about the technologies implemented at their BOF plants.

The top four energy efficiency technologies adopted by energy use project members are:

<table>
<thead>
<tr>
<th>#</th>
<th>Technology</th>
<th>Drivers for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vessel bottom stirring</td>
<td>Improves steel quality and yield and provides end-point control. Less manganese and aluminium (for tapping) are used.</td>
</tr>
<tr>
<td>2</td>
<td>Ladle temperature management</td>
<td>Improves energy efficiency which reduces energy consumption and costs.</td>
</tr>
<tr>
<td>3</td>
<td>Recycling of BOF dust</td>
<td>Leads to a higher iron-utilisation rate and higher yield. Avoids landfill costs.</td>
</tr>
<tr>
<td>4</td>
<td>Ladle lids reduce heat losses</td>
<td>Reduce heat losses</td>
</tr>
</tbody>
</table>
The three technologies which can save the most energy in a BOF plant are:

<table>
<thead>
<tr>
<th>#</th>
<th>Technology</th>
<th>Drivers for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BOF gas recovery</td>
<td>BOF gases generated during steelmaking are a valuable source of energy. BOF gas has a temperature of approximately 1,200°C and a flow rate ranging from 50 to 100 Nm³/tonne steel. Steelmakers can either flare the gas off or utilise its physical and chemical heat content to generate steam for electricity production. Total savings vary between 0.535 and 0.916 GJ/t steel, depending on how much of the gas is recovered.</td>
</tr>
<tr>
<td>2</td>
<td>Near net shape casting</td>
<td>This technology is not yet widely implemented but can play an important role in energy saving in the future. Near net shape casting reduces energy consumption by between 2.86 and 4.9 GJ/tonne of hot rolled coil by avoiding trimming in subsequent processes.</td>
</tr>
<tr>
<td>3</td>
<td>Scrap utilisation in BOF</td>
<td>The more scrap that is utilised in the BOF shop, the more energy that is saved. Energy Use project members save 13.5 GJ/tonne of scrap utilised in the BOF.</td>
</tr>
</tbody>
</table>

The BOF energy saving technologies analysed are shown in Figure 7.27. Heat recovery from BOF slag is not implemented at all BOF shops. The biggest influence on the energy intensity of the BOF shop is the amount of scrap per charge.

Figure 7.27: Implemented energy saving technologies – BOF plants

Table 7.13: List of energy saving technologies implemented at the four most energy efficient BOF plants

<table>
<thead>
<tr>
<th>Technology</th>
<th>YLOM006</th>
<th>QWCE001</th>
<th>QRDT004</th>
<th>QTOL001</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOS/BOF/LD gas recovery</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Steam generation from WHR on converter</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Vessel bottom stirring</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Near net shape casting/thin slab casting</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expert system for gas recovery</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas pressure control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous casting ratio</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Programmed ladle heating</td>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Variable speed drives of fume extraction system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
General processes and techniques

<table>
<thead>
<tr>
<th>Technology</th>
<th>YLOM006</th>
<th>QWCE001</th>
<th>QRDT004</th>
<th>QTOL001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable speed drives on gas recovery system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biofuel plant from converter gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry gas cleaning system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ladle temperature management</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>WHR on closed-loop cooling system converter (for example, Kalina Cycle)</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ladle lids used to reduce heat loss</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Single vessel blowing operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dust hot briquetting and recycling</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Recovery of high Zn concentrated pellets for external use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycling of BOF slags</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycling of BOF dusts</td>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Heat recovery from BOF slag</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regenerative burners to preheat the ladle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ID fan speed control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total implemented:</td>
<td>9</td>
<td>7</td>
<td>11</td>
<td>9</td>
</tr>
</tbody>
</table>

7.1.6.2. Average energy intensity – BOF

The most energy efficient BOF process is site YLOM006 which is 10.5% below the worldsteel reference. This comparison includes both direct and upstream energy values. The biggest influence on energy efficiency occurs in the cokemaking, ironmaking and other process upstream to the BOF process.

![Figure 7.28: Total energy intensity – BOF process](image)
Figure 7.29: Direct energy use – BOF plants

Figure 7.30: Average BOF gas recovery per tonne of crude steel
7.1.6.3. Energy intensity gap analyses – BOF process

Table 7.14: Energy intensity of worldsteel reference BOF plant compared to Eco-tech and All-tech plants

<table>
<thead>
<tr>
<th>Unit</th>
<th>Reference</th>
<th>Eco-tech</th>
<th>All-tech</th>
<th>Conversion</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot metal kg/t</td>
<td>917.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>18.28 MJ/kg</td>
</tr>
<tr>
<td>Scrap kg/t</td>
<td>130.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Lump ore kg/t</td>
<td>7.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Lime kg/t</td>
<td>45.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.05 MJ/kg</td>
</tr>
<tr>
<td>Light oil l/t</td>
<td>2.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>31.6 MJ/m³</td>
</tr>
<tr>
<td>CO gas MJ/t</td>
<td>75.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>Natural gas MJ/t</td>
<td>61.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>Fuel MJ/t</td>
<td>-</td>
<td>172</td>
<td>172</td>
<td>-</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>Electricity kWh/t</td>
<td>77.7</td>
<td>26</td>
<td>26</td>
<td>-</td>
<td>9.8 MJ/kWh</td>
</tr>
<tr>
<td>HP oxygen m³N/t</td>
<td>63.4</td>
<td>52</td>
<td>52</td>
<td>-</td>
<td>6.96 MJ/m³</td>
</tr>
<tr>
<td>Nitrogen m³N/t</td>
<td>52</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.96 MJ/m³</td>
</tr>
<tr>
<td>Argon m³N/t</td>
<td>0.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.08 MJ/m³</td>
</tr>
<tr>
<td><strong>Outputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude steel kg/t</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td>-</td>
<td>30.1 MJ/kg</td>
</tr>
<tr>
<td>BOF gas MJ/t</td>
<td>789.8</td>
<td>744</td>
<td>744</td>
<td>-</td>
<td>1 MJ/MJ</td>
</tr>
<tr>
<td>LP steam kg/t</td>
<td>-</td>
<td>60</td>
<td>60</td>
<td>-</td>
<td>3.46 MJ/kg</td>
</tr>
<tr>
<td><strong>Energy intensity</strong></td>
<td>MJ/t</td>
<td>17,674</td>
<td>-260</td>
<td>-260</td>
<td></td>
</tr>
</tbody>
</table>

Note: Missing numbers do not indicate zero consumption. Many of these inputs (and their associated energy consumption) were not taken into account in the 1998 energy report.
7.2 EAF steelmaking

The EAF production route has been divided into the following two separate processes in this report:
- Scrap-based EAF (see section 7.2.1)
- Ore-based (DRI) EAF (see section 7.2.2 below).

7.2.1. Scrap-based EAF

Project members reported data for 22 EAF plants using scrap. Of these, nine EAF plants were analysed as iron ore based processes because the amount of hot metal, cold metal, or DRI was above 50%. Four plants are located at a site which operates both BF/BOF and EAF plants. The energy intensity of five EAF sites were compared to the BF/BOF process route because of the low level of scrap input. (If less than 50% scrap is used, the process is considered as ore-based steel production.)

The average steel/scrap rate to the EAF process is 0.734 t scrap/t crude steel. The minimum steel scrap rate is 0.174 tonnes of scrap per tonne of crude steel. The maximum is 1.141 t scrap/t of crude steel.

7.2.1.1. Applied techniques and technologies – scrap-based EAF

The top four energy efficiency technologies adopted by worldsteel members in their EAF plants are:

<table>
<thead>
<tr>
<th>#</th>
<th>Technology</th>
<th>Drivers for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oxy-fuel burners</td>
<td>Electricity saving and improvement in energy intensity. Energy savings can range from 0.072 to 0.144 GJ/tonne of crude steel. However, increased oxygen consumption can decrease the energy saving potential of this technology. An air separation unit is required to maximise the savings.</td>
</tr>
<tr>
<td>2</td>
<td>Arc control</td>
<td>Electricity saving and improvement in energy intensity.</td>
</tr>
<tr>
<td>3</td>
<td>Supplementary fuel (coal injection/ waste tyres)</td>
<td>Electricity saving and improvement in energy intensity. Replacing fossil fuels with alternatives can significantly reduce the operational cost of an EAF plant.</td>
</tr>
<tr>
<td>4</td>
<td>Oxygen blowing for liquid steel oxidation</td>
<td>Electricity saving and improvement in energy intensity. Energy savings can range from 0.14 to 0.46 GJ/tonne of crude steel</td>
</tr>
</tbody>
</table>

The two technologies which reduce the amount of energy required per tonne of coke in EAF plants are:

<table>
<thead>
<tr>
<th>#</th>
<th>Technology</th>
<th>Drivers for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scrap preheating (Consteel/Vai Fuchs)</td>
<td>Scrap preheating can save between 0.22 and 0.396 GJ/t crude steel. The exact energy saving largely depends on the final temperature of the scrap before it is charged.</td>
</tr>
<tr>
<td>2</td>
<td>Hot DRI or HBI charging to the EAF</td>
<td>Hot DRI is often produced in a shaft furnace and transported to the EAF in a special bucket conveyor. The conveyor is covered and insulated to minimise temperature loss and prevent oxidation of the hot DRI during transportation. The main benefit of hot DRI charging is increased productivity and reduced electricity consumption. Energy use can be reduced by 14 to 17% compared to cold DRI charging.</td>
</tr>
</tbody>
</table>

Charging hot metal to the EAF process can save a significant amount of direct energy. If hot DRI or HBI is used, 0.54 GJ/t crude steel can be saved. If hot metal is used the saving is 1.26 GJ (350 kWh)/tonne of crude steel. However, the total energy intensity of the EAF process will be higher compared to scrap-based steel production.
Seventeen EAF steel producers (both scrap- and ore-based) reported on the energy saving technologies implemented at their plants (see Figure 7.32).

**Figure 7.32: Energy saving technologies implemented in the analysed EAF plants (scrap- and ore-based)**

The most important issues for EAF steel producers are:
- Energy (per tonne of liquid steel)
- Electrode consumption (per tonne of steel)
- Productivity (tonnes per hour)
- Tapping rate (heats per day or tap-to-tap time)

**Table 7.15: Energy saving technologies implemented at the top-four scrap-based EAF plants**

<table>
<thead>
<tr>
<th>Technology</th>
<th>QCQV001</th>
<th>JIOX003</th>
<th>JIOX002</th>
<th>QCQV003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post combustion - before the fourth hole</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Scrap preheating</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Hot pig iron charging</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot DRI charging</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxy-fuel burners</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Direct current (DC) EAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary metallurgical units (vacuum degaser)</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Oxygen blowing for liquid steel oxidation</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Oxygen blowing for post combustion</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Supplementary fuel (coal injection/charge)</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Ultra-high-power AC transformer (definition: &gt; 750 kVA/tonne)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Technology</td>
<td>QCQV001</td>
<td>JIOX003</td>
<td>JIOX002</td>
<td>QCQV003</td>
</tr>
<tr>
<td>---------------------------------------------------------------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Exhaust gas temperature and composition control</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Transformer tap changes (tap setting control)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Twin shell DC arc furnace</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous charging system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaft furnace</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Foamy slag practices</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bottom stirring/gas injection</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Arc control</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Injection of lignite coke powder for off-gas treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycling of EAF slags</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Recycling of EAF dusts</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Heat recovery from exhaust gases to generate steam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable speed driver control on fume extraction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comelt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HYTEMP®</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONARC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron carbide melting in the EAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total technologies:</td>
<td>11</td>
<td>7</td>
<td>9</td>
<td>15</td>
</tr>
</tbody>
</table>

Seventeen of the 22 analysed EAF plants reported on the energy saving technologies implemented at their plants. A total of 28 energy saving technologies were identified within the EAF process (including refining and casting). On average, ten are implemented in each EAF plant (see Figure 7.33).

![Figure 7.33: Implemented energy saving technologies – scrap-based EAF](image-url)
7.2.1.2. Average energy intensity – scrap-based EAF

The average electricity consumption of the EAF process (including the EAF furnace, refining and casting) is 558 kWh/tCS (0.0036 GJ/tCS). Figure 7.35 shows the average electricity consumption of the analysed EAF plants per tonne of crude steel.

The specific electric energy consumption can vary considerably depending on the different melting practices, burden types or EAF types.

The scrap based steelmaking route involves many different types of energy inputs. The main source of energy is still electricity through the electrodes, but in many furnaces a significant part of the total energy input comes from various types of chemical energy like oxygen, natural gas, oil, coal, non-noble metals and metallurgical dust. These fuels may be utilised in different ways (combustion in furnace, scrap preheating, melt injection) that affect the efficiency of the applied energy.
Table 7.16: Energy input to EAF plant

<table>
<thead>
<tr>
<th>Input (MJ/t)</th>
<th>QCQV 001</th>
<th>QCQV 003</th>
<th>QCQV 002</th>
<th>JIOX 004</th>
<th>JIOX 002</th>
<th>RDHE 004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthracite</td>
<td>100.3</td>
<td>0.0</td>
<td>0.0</td>
<td>169.2</td>
<td>35.6</td>
<td>388.0</td>
</tr>
<tr>
<td>EAF coal</td>
<td>125.1</td>
<td>242.3</td>
<td>233.3</td>
<td>191.8</td>
<td>224.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Pet coke</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>3.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Charcoal</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Waste tyres</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>30.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Coal</td>
<td>225.3</td>
<td>242.3</td>
<td>233.3</td>
<td>364.1</td>
<td>259.6</td>
<td>388.0</td>
</tr>
<tr>
<td>Coke</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Natural gas</td>
<td>128.4</td>
<td>144.5</td>
<td>516.5</td>
<td>651.8</td>
<td>500.3</td>
<td>362.2</td>
</tr>
<tr>
<td>Steam – LP</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Electricity</td>
<td>4,606.9</td>
<td>5,228.8</td>
<td>4,836.9</td>
<td>5,686.0</td>
<td>4,778.4</td>
<td>5,686.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Input (MJ/t)</th>
<th>QEIU 232</th>
<th>JIOX 003</th>
<th>QCAC 001</th>
<th>RIDT 414</th>
<th>RIDT 141</th>
<th>RIDT 232</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthracite</td>
<td>647.6</td>
<td>25.5</td>
<td>166.5</td>
<td>189.2</td>
<td>55.9</td>
<td>63.3</td>
</tr>
<tr>
<td>EAF coal</td>
<td>0.0</td>
<td>682.0</td>
<td>654.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Pet coke</td>
<td>0.0</td>
<td>1.4</td>
<td>67.9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Charcoal</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Waste tyres</td>
<td>0.0</td>
<td>48.9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Coal</td>
<td>647.6</td>
<td>709.0</td>
<td>888.5</td>
<td>189.2</td>
<td>55.9</td>
<td>63.3</td>
</tr>
<tr>
<td>Coke</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>190.0</td>
<td>365.8</td>
<td>206.7</td>
</tr>
<tr>
<td>Natural gas</td>
<td>419.8</td>
<td>555.0</td>
<td>414.9</td>
<td>551.8</td>
<td>507.5</td>
<td>584.8</td>
</tr>
<tr>
<td>Steam – LP</td>
<td>81.4</td>
<td>0.0</td>
<td>0.0</td>
<td>63.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Electricity</td>
<td>4,823.2</td>
<td>4,802.0</td>
<td>5,541.7</td>
<td>5,257.3</td>
<td>6,158.4</td>
<td>5,507.6</td>
</tr>
</tbody>
</table>

Figure 7.36: Raw materials used in the EAF process

The raw materials used in the EAF process are shown in Figure 7.36. Of the 22 EAF sites analysed, ten use 100% scrap input, seven sites use DRI, seven use cold iron, and one uses hot metal.

The energy intensity of the scrap-based EAF steel plants varied from 21.60% below the worldsteel reference EAF plant to 27.15% above (see Figure 7.37).
General processes and techniques

Figure 7.37: Total energy intensity of scrap-based EAF plants

Figure 7.38: Energy intensity (direct and total) of scrap-based EAF plants

7.2.2. Ore-based EAF

7.2.2.1. Average energy intensity – ore-based EAF

Nine ore-based EAF steel plants were analysed during the Energy Use project. The best performing plant was 21.95% below the worldsteel reference (defined as 6.815 GJ/t crude steel including direct and upstream energy use). The difference between the worldsteel reference plant and the analysed sites is due to the raw materials used in the EAF process. Cold iron, hot metal and DRI are the main raw materials used in the EAF process.
Figure 7.39: Energy Intensity – Ore-based EAF

Figure 7.40: Energy intensity of ore-based EAF steel production

Figure 7.41 shows the energy intensity of the analysed EAF sites (direct and total energy intensity). Direct energy intensity of these EAF plants ranges from 1.49 to 12.86 GJ/t crude steel. Total energy intensity ranges from 13.17 to 22.84 GJ/t crude steel.
General processes and techniques

Figure 7.41: Direct and total energy intensity of the EAF process

Table 7.17: List of energy saving technologies implemented at the six most energy efficient EAF plants

<table>
<thead>
<tr>
<th>Technology</th>
<th>PA00001</th>
<th>BRPR001</th>
<th>RDHE005</th>
<th>RDHE003</th>
<th>OEU010</th>
<th>RIDT323</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post combustion - before the fourth hole</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scrap preheating</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot pig iron charging</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot DRI charging</td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxy-fuel burners</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Direct current EAF</td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary metallurgical units (vacuum degasser)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Oxygen blowing for liquid steel oxidation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Oxygen blowing for post combustion</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Supplementary fuel (coal injection/charge)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Ultra-high-power AC transformer (definition: &gt; 750 kVA/tonne)</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exhaust gas temperature and composition control</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Transformer tap changes (tap setting control)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Twin shell DC arc furnace</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous charging system</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaft furnace</td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foamy slag practices</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
### Technology Drivers for Implementation

1. **Air to fuel ratio control**
   - Improves combustion efficiency and decreases scale formation. As well as saving energy, implementing this technology improves safety, environmental performance and efficiency, and product quality.

2. **Air preheating**
   - Enables waste heat recovery, saves of gas fuels, and improves energy efficiency.

3. **Waste heat recovery from exhaust gases to preheat combustion air**
   - Improves energy efficiency, saves fuel, and reduces emissions.

4. **Computer control/software model**
   - Improves energy efficiency and production quality which leads to economic savings, improved efficiency and higher productivity.

The three technologies which can save most energy in the hot rolling mill are:

<table>
<thead>
<tr>
<th>#</th>
<th>Technology</th>
<th>Drivers for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hot charge direct rolling/Hot direct rolling/Hot charge rolling</td>
<td>These technologies can save the most energy (up to 50%) at the hot rolling mill. The typical energy saving is around 0.63 GJ/tonne of hot rolled coil. Making steel to order facilitates the opportunity to reduce energy consumption. However, the steelmaking and rolling schedules must be synchronised to maximise saving.</td>
</tr>
</tbody>
</table>
### General processes and techniques

2. **Regenerative burners**
   - Hot rolling mills equipped with regenerative burners can achieve 30% better energy efficiency compared to heat recuperation after the furnace.

3. **Walking beam furnace**
   - New types of walking beam furnaces are 25 to 30% more energy efficient than regular pusher furnaces.

#### Table 7.18: List of energy saving technologies implemented at the four most energy efficient hot rolling mills

<table>
<thead>
<tr>
<th>Technology</th>
<th>JTBM001</th>
<th>PAGO001</th>
<th>QTOL001</th>
<th>PDMS002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfired preheat zone reheat furnace</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>WHR from exhaust gases to preheat combustion air</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>WHR from exhaust gases to preheat fuel</td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHR from skid system to generate steam</td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHR from exhaust gases to generate steam</td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer/combustion control models</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Slab preheating using exhaust gases</td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Door sealing (charge or discharge of furnace)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Ceramic fibre insulation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Double insulation skids</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Air cooling of skids</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Skid shifting, offset</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Computer control</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Two layer non-ox</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schedule free rolling</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Hot charge direct rolling (HCDR)</td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Hot charge rolling (HCR)</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Hot direct rolling (HDR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coil box</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Thermal covers on the transfer bar between rougher and finishing mill</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Rolling with oil</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cooling water sensible heat recovery</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen-fuel combustion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel calorific value control</td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Air to fuel ratio control</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Air preheating</td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Transfer bar edge heaters</td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>High edging facility (reduce slab width in or before roughing mill)</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>AC roughing motor</td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>
Only around a third of the available energy saving technologies have been widely implemented in the hot rolling mills of worldsteel members. The remaining technologies are not widely implemented in metallurgical plants mainly because they are not energy efficient or they are costly to implement. The World Steel Association suggests steel producers focus more on the top existing implemented technologies and work to increase their energy efficiency, reliability and availability. This will decrease the cost of implementing these technologies.

Of the 41 hot rolling mills (28 ore-based/13 scrap-based) analysed, 32 reported the energy saving technologies implemented at their HRMs (see Figure 7.42).

![Energy saving technologies implemented at hot rolling mills](image)

Figure 7.42: Energy saving technologies implemented in 32 HRMs (scrap- and ore-based)
7.3.1.2. Average Energy Intensity and Energy Efficiency – Hot Strip Mills

The average energy intensity of the hot strip mill (BF/BOF process) is 0.13 GJ/t of hot rolled coil (tHRC) above the worldsteel reference plant value. The average energy intensity of top-quartile HSM plants is 0.43 GJ/tHRC below the worldsteel reference plant.

7.3.1.3. Energy intensity trend – HRM (iron ore-based steel production)

The energy intensity of the worldsteel HRM reference plant is 20.634 GJ/tHRC. The energy intensity of the analysed HRMs ranges from 6.24% below to 3.66% above the worldsteel reference plant.
Figure 7.45: Total energy intensity of HRMs compared to the worldsteel reference plant

Figure 7.46 shows the direct and total energy intensity of the analysed hot strip mills. Direct energy intensity ranges from 0.86 to 3.04 GJ/tHRC.

Figure 7.46: Direct and total energy intensity of analysed HSMs

Figure 7.47 shows the total electricity and gas fuel input to the hot strip mills. The gas fuel input averages 56.5% (based on analyses of 17 HSMs). Reducing both gas and electricity intensity is key to operating hot strip mills effectively.
Two companies operated thin slab rolling mills in 2010. Their energy efficiency is very close to the worldsteel reference level (see Figure 7.49). The total energy intensity of the worldsteel reference thin slab rolling mill 19.944 GJ/t rolled products.
worldsteel Energy Use in the Steel Industry

Figure 7.49: Energy intensity of the analysed thin slab rolling mills compared to the worldsteel reference mill

Figure 7.50: Energy intensity of the analysed thin slab rolling mills

The energy intensity of the worldsteel reference plate mill is 24.120 GJ/tHRC. The difference in energy intensity between the best and worst performing plate mills is 24.64% (5.9 GJ/tHRC).
Figure 7.51: Energy intensity of analysed plate mills compared to the reference mill

Direct energy use of the analysed plate mills ranges from 1.64 to 6.48 GJ/t HRC. Only one plate mill exceeded the performance of the worldsteel reference mill (TLKB001).

Figure 7.52: Direct and Total Energy Intensity – Plate Mills

The energy intensity of the worldsteel long product reference plant is 20.737 GJ/t hot rolled long products (average for BF/BOF process route) from raw materials to plate. The difference between the best and worst performing long product mill analysed in this project is more than 40% (compared to total energy intensity).
7.3.2. Hot rolling mill – scrap-based steel production

Thirteen long product mills using the scrap-based steel production route were analysed in this study. The direct energy intensity of these mills ranges from 1.86 to 5.96 GJ/t hot rolled products. This compares to 2.42 GJ/t in the worldsteel reference long product mill. The total energy intensity of the reference mill is 9.48 GJ/t hot rolled products.
Figure 7.55: Energy intensity of EAF compared to reference plant

Figure 7.56: Energy intensity of scrap-based long product mills compared to reference mill
Figure 7.57: Direct and total energy intensity of analysed long product mills

7.4 Auxiliary equipment

7.4.1 Power plants

Power plants play an important role at a steelmaking site. Along with electricity, high and low pressure steam are the main products of the power plant. Both electricity and steam are distributed across the whole site. The main fuels for power plants in new modern metallurgical sites are coal and industrial gases from the coke oven, blast furnace, basic oxygen furnace and other processes. Surplus steam can be converted to electricity and used onsite or fed into the local electricity grid.

The technology most implemented by members of the Energy Use project is cogeneration of steam and electricity using industrial gases.
Figure 7.58: Energy saving technologies implemented in analysed power plants and air separation units

Data on power plants was obtained from 22 plants based at iron- and steelmaking sites. Data from three sites was omitted from the analyses because of concerns about reliability. Figure 7.59 shows the ratio between total energy input and total energy output from power plants as a percentage.

Collection of energy data from power plants seems to be a big problem for steel producers. However, power plants have the potential to offer large energy savings within sites.
7.4.2. General technologies

Eighteen metallurgical companies reported on the general technologies that are implemented. Variable-speed drives (VSD) on fans, pumps and compressors are widely implemented (see Figure 7.60). A VSD regulates the speed and rotational force (torque output) of an electric motor. VSDs can reduce energy consumption by 10 to 60% as they adapt to energy demand and run fans or pumps depending on immediate demand.
General processes and techniques

7.4.3. Air separation units

Ten metallurgical sites reported that energy saving technologies had been implemented in their air separation units.

Figure 7.60: Transferred technologies implemented in analysed plants

Figure 7.61: Technologies implemented at analysed air supply units
7.4.3.1. Contribution of oxygen to the total energy intensity of steel production

The energy needed to provide the oxygen used in steelmaking accounts for just a small part of the energy required to production steel. The exact contribution of oxygen to energy intensity depends on whether the scrap- or ore-based route is used:

- Scrap-based steel production: 0.5 to 1.5% of total energy intensity
- Iron ore-based steel production: 1.0 to 3.5%.

Figure 7.62 shows the levels of high- and low-pressure consumed at ore-based steel production sites.

Figure 7.62: High- and low-pressure oxygen consumption at ore-based steel production sites

7.4.3.2. Characteristics of air separation units utilised in metallurgical plants

Air separation units (ASUs) are widely utilised in metallurgical plants to manage industrial gases. These gases are in the following processes:

- Increasing oxygen content in the hot blast (BF)
- Basic oxygen furnace process
- Oxy fuel combustion (for example, hot rolling mill, power plant)
- Direct reduction
- EAF and reheating furnaces
- Mitigating environmental impacts
- Industrial services
- Managing inert gases such as nitrogen or carbon dioxide from conveyors, hoppers, pipelines, and other equipment
- System purging or leak testing with nitrogen
- Argon use to produce high-quality steel grades.
Typically two oxygen purity levels used: 95% for the BF and 99.5% for all other applications within a metallurgical plant. The purity is normally not dependent on the size of the ASU. Each ASU train can typically provide between 6,000 and 80,000 Nm³ of oxygen per hour.

The pressure of the oxygen depends where it is used in the metallurgical plant. For example:

- In the BF plant: 8 to 10 bar (continuous demand)
- BOF shop: 12 to 20 bar (continuous demand). Pressure of 30 bar is required to enable gas buffering for cyclic demand (non-continuous demand).

Higher oxygen pressure is need at the BOF shop as demand of oxygen is not required continuously. Oxygen is compressed to higher pressure and stored in buffers as the BOF is charged with liquid iron and scrap. The Oxygen produced for the BOF process is at higher pressure than in the BF process. It is only in the past decade that oxygen has been produced at two pressures (10 and 30 bar).

The main electricity consumers in an ASU are the compressors which account for between 93 and 95% of the energy needed to produce oxygen.

Note: Some ASUs utilise external compression. This may occur when a steel producer utilises an existing compressor which has been used in another application.

Standard ASUs have a main air compressor which first compresses air (21% O₂ content) to six bar. A second compressor increases the pressure to 60 bar. These two steps are the most energy intensive processes in an ASU.

Until 25-years ago, oxygen was produced at 1.3 bar in the ASU. An external compression system was then used to further pressurise O₂ and N₂. However, oxygen has the potential to spontaneously combust during compression, causing a fire or explosion.

Today oxygen production utilises internal compression. Compression occurs when the oxygen is in the safe liquid phase and omits the need for an external compressor. An additional advantage of internal compression is that only two compressors (main air and internal) are needed to pressurise different gases including oxygen, nitrogen and argon.

In terms of energy intensity, internal and external compression are very similar. The energy intensity of oxygen production has only decreased by 5% over the last 20 years.

The energy intensity of the oxygen plant depends on the pressure required. Producing 50,000 Nm³ of oxygen per hour results in the following energy use:

- 10 bar: 0.44 kWh/Nm³[^26]
- 30 bar: 0.51 kWh/Nm³[^26]

If a smaller ASU is used, the energy intensity of oxygen production is higher. The biggest ASU train currently in use can produce 110,000 Nm³/h[^26]. Four ASU trains, each with a capacity of 150,000 Nm³/h, are under construction. The typical operational range of ASUs in steel plants ranges from 30,000 to 60,000 Nm³/h. Steel producers prefer to build two ASUs, each with capacity of 50,000 Nm³/h, rather than one unit with double the capacity. Building two units increases the reliability of the whole process.

### 7.4.3.3. Main ASU equipment - cryogenic liquefaction

Pure gases can be separated from air by cooling the air until it liquefies, then selectively distilling the components at various boiling temperatures. The process can produce high-purity gases but is energy-intensive. The cryogenic liquefaction process was pioneered by Dr Carl von Linde early in the 20th century. It is still used today to produce highly pure gases.

[^26]: Please provide proper citation for the energy intensities.
The cryogenic separation process requires very tight integration of the heat exchangers and separation columns in order to operate efficiently. All of the energy for refrigeration is provided by compressing the air at the inlet of the unit.

To achieve the low distillation temperatures required, an ASU uses a refrigeration cycle that takes advantage of the Joule-Thomson Effect. The cold equipment must be kept in an insulated enclosure (commonly called a cold box). The cooling of the gases requires a large amount of energy to make the refrigeration cycle work. Modern ASUs use expansion turbines for cooling. The output of the expander helps drive the air compressor for improved efficiency.

The cryogenic liquefaction gas production process includes the following main steps:

1. The air is pre-filtered to remove dust.
2. Air is compressed. The final delivery pressure is typically between 5 and 10 bar. The air stream may also be compressed to different pressures to enhance the efficiency of the ASU. During compression, water is condensed out in inter-stage coolers.
3. Process air is usually passed through a molecular sieve bed which removes any remaining water vapour and carbon dioxide which can freeze (and plug) the cryogenic equipment. Molecular sieves are often designed to remove any gaseous hydrocarbons from the air as these can lead to explosions in subsequent air distillation steps. The molecular sieve beds must be regenerated. This is done by installing multiple units which operate alternately. The dry, co-produced waste gas is used to de-adsorb the water.
4. Process air is passed through an integrated heat exchanger (usually a plate fin type) and cooled against the cryogenic product (and waste) streams. Part of the air condenses to form a liquid which is rich in oxygen. The remaining gas is richer in nitrogen and is distilled to almost pure nitrogen (typically < 1ppm) in a high pressure distillation column. The condenser in the column requires refrigeration. This is obtained by expanding the rich oxygen stream further across a valve or through an expander (a reverse compressor).
5. Alternatively the condenser may be cooled by interchanging heat with a re-boiler in a low pressure distillation column (operating at 1.2 to 1.3 bar) when the ASU is producing pure oxygen. To minimise the cost of compression, the combined condenser/reboiler of the high and low pressure columns must operate at a temperature difference of only 1 to 2 degrees Kelvin. This requires brazed aluminium plate-fin heat exchangers. Typical oxygen purity ranges from 97.5% to 99.5% and influences the maximum recovery of oxygen. The refrigeration required to produce liquid products is obtained by exploiting the Joule-Thomson Effect in an expander which feeds compressed air directly to the low pressure column. Part of the air is not separated and must leave the low pressure column as a waste stream from its upper section.
6. Because the boiling point of argon (-185.85°C at standard conditions) lies between that of oxygen (-182.95°C) and nitrogen (-195.75°C) this gas builds up in the lower section of the low pressure column. When argon is produced, a vapour-side draw is taken from the low pressure column where the argon concentration is highest. The gas is sent to another column where the argon is processed to achieve the required purity. Liquid is returned to the same location in the low pressure column. As modern structured packing is used there are very low pressure drops which enable argon to be produced with impurities of less than 1 ppm. Although argon is only present in less than 1% of the incoming air, the argon column requires a significant amount of energy due to its high reflux ratio (about 30). Cooling for the argon column can be supplied from cold expanded rich liquid or liquid nitrogen.
7. The gas products are warmed against the incoming air to ambient temperature. This requires carefully crafted heat integration which provides protection against disturbances such as the switchover of the molecular sieve beds. It may also require additional external refrigeration during start-up.

The separated products are sometimes supplied by pipeline to large industrial users near the production plant. Long distance transportation of gas requires liquid product for large quantities or gas cylinders for small quantities.

### 7.4.3.4. Main ASU equipment – non-cryogenic processes

The pressure swing adsorption (PSA) process enables oxygen or nitrogen to be separated from air without liquefaction. The process operates at ambient temperature. In the PSA process, a zeolite (molecular sponge) is exposed to high-pressure air. When the air is released, an adsorbed film of the targeted gas is released. The size of the compressor is much smaller than that need in a liquefaction plant. Portable units are available and are typically used to provide oxygen-enriched air for medical purposes.

A variation on PSA is the vacuum swing adsorption process (VSAP). In VSAP, the product gas is evolved from the zeolite at sub-atmospheric pressure.

Membrane technologies can provide alternate, low-energy approaches to air separation. A number are being explored for their oxygen generation potential. For example, polymeric membranes operating at ambient or warm temperatures may be able to produce oxygen-enriched air (25 to 50% oxygen). Ceramic membranes can provide high-purity oxygen (90% or more) but require higher temperatures (800 to 900ºC). Ceramic membranes under development include ion transport membranes (ITM) and oxygen transport membranes (OTM). Air Products is developing a flat ITM, while and Chemicals Inc. and Praxair are developing tubular OTM systems.

![Figure 7.63: Schematic of an air separation unit](image-url)
7.4.3.5. ASU design and energy intensity reduction

Further reductions in the energy use of ASUs are expected to be realised by 2015.\[22\]

The energy use of an ASU could be reduced by:

- Building larger and more energy-efficient ASUs
- Developing new process cycles
- New developments in technology.

\[\text{Figure 7.64: ASU Energy Intensity}\[22\]]

Oxy-combustion is the most efficient route for carbon capture and sequestration. The advanced cryogenic ASU concept represents a potential breakthrough for the oxy-combustion route.

Further reductions in the power consumption of an ASU and the capital expenditure required to implement them are necessary. One way to achieve this is by improving the efficiency of the main compressors.

Hybrid ASUs utilise membrane filters to increase the level of oxygen in the air before the first compression. The membranes increase the oxygen content of the air to between 30 and 40%. This can reduce the energy intensity of the ASU by an estimated 30 to 35%.

Steel producers should find more effective ways to utilise oxygen at their steel plants. For example, if the BOFs can be better coordinated (by synchronising the operation of converters), there is no need to use buffers at the steel shop. In this case pressure can be reduced from 30 to 15 bar which cuts the energy intensity of the ASU by a minimum of 10%.

7.5 Site energy intensity

This section describes the energy intensity of steel production sites. It uses the roll-up methodology described in section 5.1.4.
7.5.1. Iron ore-based steel production – roll-up results

7.5.1.1. Primary metal level

The energy intensity of 26 iron ore based steel production sites were analysed. Seventeen sites have implemented an integrated steel production route (BF/BOF process route). Three companies have implemented a BF/BOF and EAF process route (PAGO001, QWCE001 and RZLD101) while six sites have implemented EAFs with DRI input higher than 50%.

From analyses it is evident the DRI/EAF process route has a higher level of energy intensity compared to the BF/BOF process route. Only one site (BRPR001) is close to the worldsteel reference (mainly because this site has implemented hot DRI charging to the EAF). Generally the DRI/EAF process route is 25% more energy intensive than the BF/BOF route.

![Primary metal production (Iron ore based steel), Year:2010](image)

Figure 7.65: Primary metal production roll-up (ore-based steel production)

7.5.1.2. Semis level
Figure 7.66: Semis roll-up (ore-based steel production)

7.5.1.3. Hot rolled level

Figure 7.67: Hot rolled product roll-up (ore-based steel production)
7.5.2. Site level

Figure 7.68: Site roll-up (ore-based steel production) including power plant, ASU and flares

7.5.3. Scrap-based steel production – roll-up results

Thirteen metallurgical sites with a scrap-based steel production route were analysed. Sites RIDT414 and RIDT232 charge cold iron into the EAF, while site RZLD001 utilises DRI. Based on available literature, the energy intensity of these sites should be lower than that of an EAF plant which uses 100% scrap. However, the results do not reflect this and the opposite is true in these examples. The energy saving correction factor for pig (cold) iron is 1 kWh per tonne of crude steel energy for each 1% of pig iron charged in the EAF. This balances the actual energy used and covers the change in the carbon content of pig iron (approximately 4.2%) which is reduced to below 0.8% carbon in the steelmaking process.

The energy intensity of the EAF process goes up when you increase the percentage of DRI in the charge. On the basis of available literature, the DRI correction factor is defined as 200 kWh/t DRI. This value is in line with the value obtained from the real-life experience of Energy Use project members (217 kWh/t DRI). The project team decided to utilise the correction value of 217 kWh/t DRI in the energy survey as it is based on practical experience.

7.5.3.1. Semis level (scrap-based) – roll-up
Figure 7.69: Semis level roll-up (scrap-based steel production)

7.5.3.2. Hot rolled level (scrap-based) – roll-up

Figure 7.70: Hot rolled level roll-up (scrap-based steel production)
General processes and techniques

7.5.4. Site level (scrap-based) – roll-up

![Graph showing site level roll-up (scrap-based steel production). Includes power plants, ASUs and flares](image)

Figure 7.71: Site level roll-up (scrap-based steel production). Includes power plants, ASUs and flares

7.6 Industry-wide horizontal measures

7.6.1. Energy management systems

Some industry participants have observed that up to 30% of their achieved energy savings are linked to improvements in energy management strategies.

Many years of experience, and this report, have demonstrated that it is quite difficult to analyse energy performance from overall figures. This is largely due to the variability in specific consumption.

Global figures show that improvements (and in some cases increases) in energy intensity can be impacted by factors such as production volumes, the charge mix, quality of raw materials, product mix, technologies deployed in the plant, and environmental mitigation techniques. These variables can affect overall key performance indicators (KPIs) and may give an inaccurate picture of improvements if not assessed correctly.

To accurately reflect the trend in the energy efficiency of the iron and steel industry, all factors influencing energy efficiency must be understood and included. Only an accurate, well-organised energy management system which covers all industry functions can ensure that energy is fully optimised.

The steel industry is committed to developing a long-term business and aims to improve the energy efficiency of its operations for both strategic, environmental, health and safety, and economic reasons. The goal of improving energy efficiency cannot be reached with investments or breakthrough technologies alone. An energy management system is required which sets clear objectives, controls and action plans.
The key pillars of an effective energy management system include:

- Systemic energy management in order to reduce costs, energy intensity and emissions to the atmosphere, and provide a healthy and safe environment.
- Raising awareness of the need to eliminate unnecessary energy consumption in all aspects of steel production. Paying attention to the use of environmental resources is a shared cultural value. This must be clearly communicated to everyone involved in the business and become an active focus for all departments.
- Researching, designing, and implementing effective technologies to optimise the overall energy consumption of a plant.
- Identifying and managing all the systems that use energy through precise rules of conduct and adequate training of assigned personnel.
- Providing financial, organisational, and human resources dedicated to the constant control of energy intensity.
- Establishing objectives for continuous improvement in all activities which use energy. Efforts should be concentrated on identifying the best energy saving opportunities.
- Analysing data related to planned consumption targets and implemented improvement plans. By measuring the effectiveness of existing efforts and defining corrective actions, further improvement can be made.

Since 2009, new standards for energy management in the steel industry have been developed by international (ISO) and European standardisation agencies. Both agencies are developing methods to measure the CO₂ and greenhouse gas performance of the iron and steel industry.

The worldsteel Association established this working group in order to benchmark the energy intensity of its members. It is clear that through efforts such as this, the steel industry is continuously improving its ability to manage energy.

Many industries have unified their efforts to establish local, national or even global energy management plans. Initiatives have included coordinated goal setting, waste reduction, investment, planning and training, including complementary industries in industrial parks, and linking to the energy grid to level out peak demand.

The ultimate goal is to create a cultural change which inspires employees, companies, and regional and national distribution managers to look for ways to increase the energy efficiency of their operations and reduce the resulting CO₂ emissions.

A complete energy management programme must also include the following steps:

- A holistic assessment of energy use in the overall process.
- Detailed understanding of the value-chain energy intensity using a roll-up process.
- A formal master plan for energy investments.
- Promotion of the rational use of energy through training and waste reduction activities.
- Continuous improvements and ensuring existing equipment and processes are available and reliable.
- Standardisation of highly efficient equipment and designs.
- Measuring, benchmarking, controlling and reporting through the implementation of online systems, KPIs and reports.
The programme must also ensure that the cultural approach to energy usage must be relentlessly and accurately managed through ongoing benchmarking and following a well-considered path.

To achieve all the improvements in energy intensity possible, an energy management system is required. It must be guided by processes and procedures and be part of a company energy policy and objectives. It has to be led by a team who can combine their knowledge of energy use with sound governance and diligent management. Improvements must be economically viable, financially acceptable and communicated to all stakeholders in and outside the business. It is essential that a sufficient level of energy management personnel are employed with the skills to implement, maintain and improve energy intensity goals.

**Figure 7.72: Example of an energy management system**

The diagram illustrates the key components of an energy management system, including cultural change, energy saving, industrial energy efficiency, energy consumption audit, management, engineering, purchasing, operations, maintenance, investments, reduce future ineffectiveness and prevent waste, reduce product cost, reduce energy use, and correct past ineffectiveness.

- **Energy consumption audit**
- **Industrial energy efficiency**
- **Management**
- **Engineering**
- **Purchasing**
- **Operations**
- **Maintenance**
- **Investments**
- **Cultural change**
- **Reduce environment impact**
- **Reduce product cost**
- **Reduce energy use**
- **Correct past ineffectiveness**

This system is designed to optimize energy use, reduce costs, and improve environmental impact through a comprehensive approach that integrates cultural change, governance, and management practices.
8. **Energy saving potential of the steel industry**

One of the main outcomes from the new worldsteel energy intensity calculation methodology is the ability to calculate the energy saving potential of a metallurgical site. Energy saving potential is calculated by comparing the known energy performance of a process to the worldsteel reference values.

### 8.1 Metallurgical processes – energy saving potential

Table 8.1 shows the energy saving potential of the analysed metallurgical processes in the BF/BOF route. The energy saving potential was calculated only for processes where the energy intensity was above worldsteel reference levels.

**Table 8.1: Energy saving potential of the BF/BOF process (based on 2010 volume)**

<table>
<thead>
<tr>
<th>Metallurgical processes</th>
<th>Total energy saving (TJ/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air separation unit</td>
<td>5,235.0</td>
</tr>
<tr>
<td>BF</td>
<td>159,160.0</td>
</tr>
<tr>
<td>BOF</td>
<td>146,039.0</td>
</tr>
<tr>
<td>Cokemaking</td>
<td>41,394.0</td>
</tr>
<tr>
<td>DRI</td>
<td>954.0</td>
</tr>
<tr>
<td>EAF</td>
<td>20,803.0</td>
</tr>
<tr>
<td>Flared gas</td>
<td>36,612.0</td>
</tr>
<tr>
<td>HSM (carbon)</td>
<td>13,602.0</td>
</tr>
<tr>
<td>Ingot cogging mill</td>
<td>22,582.0</td>
</tr>
<tr>
<td>Long products</td>
<td>25,595.0</td>
</tr>
<tr>
<td>Pellet plant</td>
<td>795.0</td>
</tr>
<tr>
<td>Plate mill</td>
<td>3,740.0</td>
</tr>
<tr>
<td>Power plant</td>
<td>58,546.0</td>
</tr>
<tr>
<td>Sinter plant</td>
<td>41,492.0</td>
</tr>
<tr>
<td>TSR</td>
<td>253.0</td>
</tr>
</tbody>
</table>

The total energy saving potential of the analysed sites is 576,007 TJ/year (see below for energy intensity saving per tonne of steel produced).

This energy saving is theoretical and assumes that all sites will reach the worldsteel reference level.

### 8.2 Metallurgical sites – energy saving potential

Data analysed as part of this project has shown that a significant reduction in energy intensity can be achieved for both the BF-BOF and EAF process routes. This requires better management decisions, more effective operations, production efficiency, and higher yield. It appears that it is possible to achieve the worldsteel reference values without necessarily having all of the latest technologies installed at a plant.

Monitoring operations allow better management of energy usage and improve process reliability. Rework is reduced and energy savings are made as auxiliary systems (such as cooling water pumps or gas for heating) only operate when required.
8.2.1. BF/BOF process – energy saving potential

The average energy intensity of the BF/BOF plants analysed for this report is 19,314.4 MJ/tCS. This includes sintering and cokemaking. The worldsteel reference value for the BF/BOF plant is 17,674 MJ/tCS. This calculation includes all processes up to the BOF plant (crude steel production).

The potential reduction in energy intensity is 1.64 GJ/tCS if companies move from an average level to that of the worldsteel reference plant.

In value terms, this translates to a potential saving of US$67/MWh in Europe. This equates to a saving of US$30.54/tonne (1.64 GJ/tonne x 0.278 GJ – MWh conversion factor x $67/MWh = $30.54 per tonne). In North America, where energy costs are approximately one-fifth that of the EU, the saving is still US$4.67/tonne. In other regions the potential savings depend on the cost of energy locally.

In Europe, additional savings can be made by reducing emission trading costs. As energy use is directly related to CO₂ emissions, a 9.28% reduction in energy use translates to a 9.28% reduction in CO₂ emissions. To produce a tonne of steel using the BF/BOF route, 2.18 tonnes of CO₂ is emitted. Reducing emissions by 9.28% can therefore reduce costs by €1.01 per tonne (9.28% x 2.18 CO₂ intensity x €5/tonne = €1.01 or US$1.34/tonne).

An electricity conversion factor of 3.6 MJ/kWh was assumed for these cost-saving calculations.

8.2.2. EAF process – energy saving potential

Using the EAF route, potential savings are lower. The EAF route uses less processes and therefore less electricity as direct energy. The potential saving is 11.3% or 0.77 GJ/tonne of crude steel (average EAF energy intensity is 7.58 GJ/tonne of crude steel while the reference energy intensity is 6.81 GJ/tonne).

This potentially saves US$67 per MWh in the EU which equates to US$14.34/tonne of crude steel (0.77 x 0.278 x 67 = US$14.34 per tonne).

Again, in North America the saving is less due to the lower price of energy compared to Europe.

The above calculations are valid for the parameters available at the time this report was prepared. Savings will be different for each organisation and depend on the local cost of energy. Companies can use the above calculations with their own energy costs to calculate the potential savings.

8.3 Influence of technologies and practices on energy intensity

8.3.1. Scrap

Scrap has the biggest impact on the energy intensity of steel production. Each tonne of scrap used at the integrated steelplant saves 13.25 GJ of energy. The average scrap utilisation ratio in the BOF processes studied is 152 kg of scrap/tCS (approximately 15%). Two sites do not utilise any scrap at their BOF plants. This causes their total energy intensity to be proportionally higher compared to the worldsteel reference plant and other analysed sites. The maximum scrap rate to the BOF process is 371 kg/tCS (37%) but this may not be the limit.

Scrap availability in China is likely to increase once the first recovery cycle starts for the products produced during the 2000 – 2010 period. This is likely to start from 2025 onwards and will have a significant impact on iron ore demand and, potentially, on the cost of iron ore worldwide. The same phenomena may occur in India and other developing countries in Asia as the recycling cycle starts. It will have a significant effect with scrap becoming competitive with iron ore and coal use.
Scrap availability in China is expected to quadruple between 2010 and 2030. With 100 million tonnes of scrap available in China during 2010, scrap availability is likely to reach 350 to 450 Mt/year by 2030. The increased usage of scrap in BOF steelmaking will decrease the need for hot metal production proportionally. It is likely that EAF units will replace smaller or inefficient BFs that are due for reline or re-investment at existing integrated sites. At the same time, BOFs will be able to increase the percentage of scrap used. Any new capacity is likely to be comprised of mini-mill units or, moving to the next step in steelmaking technology, using the direct casting to rolling or other processes developed by companies such as Arvedi, Siemens VAI, NUCOR, BSL, and Castrip.

![Theoretical Scrap Availability in China](image1)

**Figure 8.1: Theoretical steel scrap availability in China**

![Global Raw Steel Production Outlook by Region](image2)

**Figure 8.2: Global raw steel production outlook by region**

The long-term growth rate of steel production is certain to moderate from recent levels, with developing economies driving 2.7% annual growth.
8.3.1.1. Scrap influence on the energy intensity of the BOF process

![Energy intensity of the BOF process](image)

**Figure 8.3: Energy intensity of the BOF process**

The amount of scrap used as an input to the BOF process ranges from zero to 371 kg/tCS. Two sites reported zero scrap input to their BOF plants. This is a reason for their poor energy intensity compared to other companies.

If these two sites utilised the worldsteel reference scrap input to the BOF (130.4 kg scrap/tCS) their BOF energy intensity, and that of their whole site, would put them in the list of top five companies.

![Average scrap input to the BOF process](image)

**Figure 8.4: Average scrap input to the BOF process**

Based on Figure 8.3 and Figure 8.4, it is evident that scrap has the biggest influence on energy intensity (the best BOF plants utilise the most scrap). Companies with the highest scrap input to the BOF process have the lowest total energy intensity, even though these companies recover little or no BOF gas.

The ratio of scrap input to the BOF process doesn't have a significant influence on high-pressure oxygen consumption (see Figure 8.5).
Figure 8.5: High pressure oxygen consumption in BOF processes

The energy intensity of the company with one of the lowest levels of scrap input to the BOF process is 15.47% above the worldsteel reference. Every 10% increase in scrap to the BOF process reduces energy intensity by 0.8 GJ/tCS (see Figure 8.6).

Figure 8.6: Energy intensity improvement of BOF processes with higher scrap input

The same analyses of scrap’s influence on the metallurgical site’s energy intensity were conducted. A 10% increase in scrap improves site energy intensity by 1.6 GJ/tCS (see Figure 8.7).
Energy saving potential of the steel industry

8.3.1.2. Influence of scrap/DRI on the EAF process route

Figure 8.7: Improvement in energy intensity for integrated site using higher scrap input to BOF

Figure 8.8: Total energy and CO₂ intensity for the DRI/EAF route

100% scrap based EAF CO₂ intensity: 0.39 t CO₂/tCS
100% DRI/EAF CO₂ intensity: 1.44 t CO₂/tCS
Figure 8.9: Direct energy and CO₂ intensity for the DRI/EAF route

100% scrap based EAF CO₂ intensity: 0.39 t CO₂/tCS
100% DRI/EAF CO₂ intensity: 0.50 t CO₂/tCS

Steel recycling uses:
- 74% less energy
- 90% less virgin materials
- 40% less water

Steel recycling produces:
- 76% fewer water pollutants
- 86% fewer air pollutants (CO₂ emissions are reduced by 58%)
- 97% less mining waste
- 2.3 cubic meters less landfill.

If more scrap is recycled and utilised in steelmaking, it means quality and cost pressures are transferred to the mining industry.

8.3.2. Energy saving technologies implemented in metallurgy sites

One of the main goals of this project was to analyse the penetration of energy saving technologies in the steel industry. (A discussion of the main energy saving technologies used can be found in chapter 7 - General Processes and Techniques.)

It is possible to analyse the potential savings of all energy saving technologies in use within the industry.

For example, 13 steel companies reported information about PCI injection to the BF. The average PCI injection rate (over a whole year of operations) within BF sites with existing PCI technology is 140 kg/tHM (91 kg PCI rate within all analysed BF plants). The average minimum PCI injection was 89 kg PCI/tHM, while the average maximum was 174 kg PCI/tHM.
Energy saving potential of the steel industry

Two cases were analysed within this study.

1. If energy use project members achieved an injection rate of 180 kg PCI/tHM the energy saving is 0.42 GJ/tHM. It is easy to reach this injection rate with existing technologies and can be implemented at each BF without the need for significant oxygen enrichment.

2. If an injection rate of 220 kg PCI/tHM is achieved, the energy saving is 0.61 GJ/tHM. This level of PCI is more difficult to reach but a lot of BFs already operate at this level worldwide.

Note: the same analyses can be prepared for other energy saving technologies.

The exchange rate between coke and PCI ranges from 1.1 to 1.2 kg of PCI/tonne of coke (1.3 to 1.4 tonnes of coking coal saved at the coke plant).

The highest known PCI injection rate/tHM is in the range 230 to 250 kg. However, it is not possible to reach this PCI injection rate at every BF. If high levels of PCI are used, the quality of the remaining coke has to be very high, although the volume is reduced to ensure the permeability of the burden. Energy saving technologies have operational and technological limitations due to factors such as the specific production and operational performance, raw material quality, and operational practices.

Figure 8.10 shows the average coke and PCI injection rate to the BF within the sites studied (per tonne of hot metal).

![Figure 8.10: Coke and PCI rate to BF in studied sites](image-url)
8.3.2.1. Penetration of energy saving technologies

Installing energy saving technologies has been the main task for steel producers who want to reduce their energy intensity. The installation of new technology has to be considered very carefully and its influence on other processes and the site must be analysed. It is recommended that the analysis is carried out using the worldsteel methodology and its online system.

Project members collected information about the energy saving technologies implemented within their sites. The results are shown in Figures 8.11 and 8.13.

Site PAGO001 has the most implemented energy efficiency technologies. This company has installed a BF/BOF and a EAF process route within their site. The number of energy saving technologies implemented by project members varies widely and doesn’t follow the energy intensity curve as expected.

Companies RDHE005, RDHE003, RIDT323, BRPR001 and QEIU110 operate EAFs with DRI input higher than 50%. Metallurgical companies have implemented an average of between 30 and 40% of the existing energy saving technologies available (based on the worldsteel list of energy saving technologies).

Figure 8.11: Energy intensity of iron ore based steel production route compared to the number of implemented energy saving technologies

Figure 8.12 shows the energy intensity of DRI sites compared to the number of implemented energy saving technologies. Six DRI sites were analysed within the energy use project. Between 17 and 35 energy saving technologies were implemented within these analysed DRI sites.
The energy saving technologies implemented in EAF plants are more balanced (see Figure 8.13). The average number of energy saving technologies implemented is 23. The energy intensity of the EAF processes used by members of this project range from -26.24% below the reference level to +68.00% above. The very wide difference is due to the type and quality of raw materials used in the EAF plant.

The penetration of energy saving technologies in EAF plants is more consistent than in the BF/BOF process route.
Another example is the analyses of energy saving technologies implemented in metallurgical sites compared to the potential energy saving. Figure 8.14 shows the number of energy saving technologies implemented within the BF plants studied compared to their energy saving potential. Based on this graph we can say that the technologies which produce the biggest energy savings are: BF injectants, BF gas recovery, top recovery turbines, and waste heat recovery from molten slag.

Only BF injectants and gas recovery technologies are widely implemented at project member sites. It means there is future potential for further improvements in energy intensity if these technologies are further developed (for example, waste heat recovery from molten slag) and more widely implemented at metallurgical sites.
8.3.3. Shale gas availability in US and rest of the world

The United States is utilising the shale gas revolution to create an abundant supply of gas, low prices, and considerable economic benefits. The US shale gas price is predicted to range between US$5 and US$7 per million British thermal units (MMBtu) for the next 20 years. That is one-fifth the predicted cost of energy in Europe and the rest of the world.

Big shale gas deposits have been discovered around the world. The largest are in China (see Figure 8.16). Shale gas will stimulate the use of DRI as natural gas prices drop significantly. It will be a key resource for many countries in the future, not just those in North America. Shale gas can be also injected into the BF.

The impact of shale gas on the BF/BOF route compared to the DRI/EAF route, and its impact on global steelmaking is yet to be determined. Many countries are considering exploiting this vast resource over the next decade in order to stimulate industry and provide a source of energy which is significantly cleaner than extracting coal for electricity generation.

Figure 8.14: Level of energy saving by technology

Energy saving potential of the steel industry
8.3.4. Energy intensity of BF/BOF compared to DRI/EAF processes

The average energy intensity of the BF/BOF and DRI/EAF production routes have been analysed to understand the energy use difference between the two processes.
Energy saving potential of the steel industry

The energy intensity of the DRI/EAF process is 20% higher than that of the worldsteel reference BF/BOF. However, CO₂ production in the DRI/EAF production route is 34% lower on average compared to the BF/BOF process when DRI is used with natural gas (source: worldsteel database).

Figure 8.17 shows the BF/BOF sites, offset against the worldsteel reference plant (22 BF/BOF sites were analysed in this study). It also shows the energy intensity of DRI/EAF sites offset to the worldsteel reference plant (six DRI/EAF sites analysed).

Figure 8.17: Comparison of average energy intensity for BF/BOF and DRI/EAF process routes

Blue bars represent BF/BOF sites, red bars represent DRI/EAF sites, while green bars represent sites with both BF/BOF and EAF plants. The orange bar shows the smelting reduction process.

Figure 8.18 shows the difference between the direct and total energy intensity of the EAF plants studied.
8.3.5. Effect of yield losses on the energy intensity of steel production

The following definitions are used in this section:

Yield loss: The efficiency of a process calculated by comparing the weight of output to the weight of input. Ferrous yield, for example, measures the quantity of iron atoms introduced into the steelmaking process which end-up as steel product.

Yield: In physical metallurgy, the effect of material elongation as a consequence of applied stress.

8.3.5.1. Ironmaking and hot metal treatment

Significant yield losses can occur during tapping, handling, and treatment of hot metal. In particular, iron can be tapped along with slag during slag removal (after hot metal desulfurization). Yield losses of 1 to 3% are typical. A 1% yield loss of liquid pig iron equates to an energy loss of 0.104 GJ. If the iron is recovered from the slag and reused, only the sensible and melting energy (about 14 MJ/tHM) is lost.

8.3.5.2. Steelmaking

Yield losses in both BF and EAF steelmaking can be significant. The highest yield loss is iron to the slag, which can be approximately 5 to 10%. The yield loss releases energy and is included in the energy intensity calculation. More iron must be charged to compensate for the loss of volume. This effect is taken into account in the results given for the BOF and EAF. However, there is no energy charge for the increased use of scrap. Other yield losses can occur from vaporisation of iron (which is oxidised into dust), other iron losses into dust, and during tapping and handling.
Vaporisation of iron consumes a considerable amount of energy in steelmaking. The energy is not recovered when the vaporised iron is oxidised in the off-gas. If 1% of the iron vaporises in the BOF and there is no energy recovery from iron oxidation, the energy loss equates to the energy required to make the steel (80 MJ) plus the heat of vaporisation (64 MJ) – a total of 0.144 GJ per tonne of steel. Typical losses from vaporisation are about 0.5 to 1.0%. If 1.0% of the iron vaporises in the EAF, the invested energy in the steel is less (13 MJ), while total energy loss is 0.077 GJ.

The direct energy lost through vaporisation (64 MJ) can cause a larger decrease in energy for BOF steelmaking. The energy loss will result in less scrap being melted, which will cause a shift from scrap to hot metal. Since making hot metal requires considerably more energy than melting scrap, the resulting increase in energy could be as high as 0.5 GJ.

Iron is also lost to dust though simple metal ejection. In this case, only the energy invested is lost. Again, the iron is oxidised in the off-gas and is not recovered. A 1.0% yield loss caused by ejected metal equates to an energy loss of 80 MJ for BOF and 16 MJ for EAF steelmaking. The vaporisation and loss of other metals, such as zinc, is possible but not considered.

**8.3.5.3. Direct reduction**

In making DRI, some material is lost as fines during the production of DRI/HBI. This material is often recovered and used to form briquettes or injected into an EAF, in which case there is little energy loss. However, if the material is lost (or more likely, recycled back into the direct reduction furnace), some or all of the heat energy contained in the material is lost. Assuming that the material does not re-oxidise and is recycled into the process, the energy loss is 6.2 MJ/t for every 1% of material recycled. If the material is re-oxidised, the energy loss per 1% is 84 MJ/t.

**8.3.5.4. Rolling**

Yield loss during rolling usually occurs because of a loss of material during scarfing, oxidisation in the re-heat furnace, or during the cutting of transfer bars and coils to obtain clean ends. The yield loss is usually re-melted, requiring about 13 MJ/t for a 1% loss of iron.

However, yield loss often occurs later in the process, when additional energy has been invested into the steel. For example, if the slab is reheated and hot rolled, the yield loss after cold rolling results in a 34 MJ/t loss. If the iron is oxidised or not recovered, the invested energy in the steel is lost. A 1% yield loss applied to the most likely production cases represents an additional loss of 80 MJ/t for BOF steel and 16 MJ/t for EAF steel.
9. Energy source utilisation in metallurgical plant

9.1 Industrial gas input rate to metallurgical processes

Figure 9.1 shows the rate of gas fuel input to the coke oven battery at project member’s sites. Coke oven gas and BF gas are the most widely used industrial gases in the cokemaking process. The utilisation rate of BF gas ranges from 12.94 up to 84.75%. Coke oven gas utilisation rates vary from 9.63 up to 86.84%. Utilisation of other gases is limited within the coke oven plant. Natural gas can be used as a safety fuel in case of emergency.

Figure 9.1: Gas fuel input to the coke oven process

Figure 9.2 shows the gas fuel input (including industrial, natural and other gases) into the sintering process. Seventeen sinter plants were analysed within this project. Seven utilise 100% coke oven gas while four use natural gas. Only six sinter plants utilise a mix of industrial gases and natural gas.
Figure 9.2: Gas fuel input to the sintering process

Figure 9.3 shows gas fuel input to the four pelletizing plants analysed for this report. Coke oven gas is used as the main fuel in the pelletizing processes.

Figure 9.3: Gas fuel input to the pelletizing plant
Figure 9.4 shows the gas fuels used in the BF process. BF gas is used most often as an energy input to the BF process itself (ranging from 30.7 to 100% input).

Figure 9.4: Gas fuel input to the BF process

Figure 9.5 shows the gas fuel input rate to the BOF process. Natural gas and coke oven gas are the main gas fuels used in a BOF process.

Figure 9.5: Gas fuel input to the BOF process
Energy source utilisation in metallurgical plant

Figure 9.6: Gas fuel input to the HSM process

Figure 9.6 shows the gas utilisation ratio for hot strip mills operated by project members worldwide. Gas input to the hot strip mill reheat furnace represents the biggest energy input to the HRM. The main fuel is coke oven gas. It can be mixed with other industrial gases or natural gas to obtain the required heating value before combustion. It can be used in pusher or walking-beam furnaces to reheat slabs, billets or bars.

The use of industrial gases in the hot rolling mill or power plants is a recent development. For energy specialists, the challenge is to find effective ways to balance and utilise these fuel-rich gases.

Figure 9.7 shows the mix of gas fuels used in the power plants analysed as part of this study. Industrial gases are generally combusted in gas furnaces, gas turbines or coal/gas boilers. The steam and electricity produced is typically utilised within metallurgical plants. Onsite electricity production covers from 40 to 60% of the plant’s total electricity consumption. Additional electricity is purchased from external sources. BF gas is the most utilised gas in power plants operated by project members.
9.2 Destination of industrial gases

9.2.1. Destination of coke oven gas

Utilisation of coke oven gas is very effective within metallurgical plants. Some steel companies only flare a small amount of coke oven gas which means their utilisation ratio is close to 100%. In an emergency shutdown, gas can be diverted and burnt on flares.

Coke oven gas is widely used across metallurgical sites. The top three uses are in cokemaking, the hot strip mill and power plants (see Figure 9.8).
Energy source utilisation in metallurgical plant

9.2.2. Destination of BF gas

The amount of BF gas used within plants is very high. The top three uses are in the BF itself, power plants and coke oven plant. Other gas with a high heating value (such as coke oven or natural gas) is usually mixed with BF gas to increase the initial heating value and secure the combustion process.
9.2.3. Destination of BOF gas

Basic oxygen furnace gas utilisation is limited within some metallurgical plants. Of the sites studied for this report, more than 22% burn BOF gases on flares. If the utilisation rate of this gas could be increased, steel producers would save additional energy. However, it is not possible to capture and utilise all the BOF gas produced during steel production because of its low CO content at the beginning and end of oxygen injection to the BOF converter. The top three destinations for BOF gas are the power plant, hot strip mill, and long product mills.

![Pie chart showing destination of BOF gas]

Flares are still used to burn off excess gas. This study found the following flare rates for common industrial gases:

- Coke oven gas: 2.46%
- BF gas: 5.9%
- BOF gas: 26.4%

The biggest energy saving potential for steel producers is better utilisation of BOF gas within their plants. The main goal of steel producers is to minimise the amount of industrial gas that is burnt on flares and to find efficient uses for these gases in their metallurgical processes.

Figure 9.11 shows the industrial gases burnt on flares, as reported from 22 metallurgical sites. The first five sites did not report on the use of industrial gases in flares. During normal operations these plants are not allowed to burn any industrial gases on flares.

An average of 0.513 GJ of industrial gas/tCS are combusted on flares. This represents a significant energy saving opportunity for steelmakers.
9.3 Energy intensity indicators

9.3.1 Energy intensity indicator for BF/BOF process route

The main fuel input to the metallurgical plant (from iron ore up to slab production) was analysed for 19 metallurgical sites with a BF/BOF process route. The average energy intensity indicator for these sites is 22,164 MJ/t slab.

Figure 9.11: Industrial gases combusted on flares (project member sites)
9.3.2. Energy intensity indicator for EAF process route

Figure 9.12: Energy input to the BF/BOF process route (average data from project members)

Figure 9.13: Fuel input to the EAF process route (weighted average data from project members)
10. Conclusion

The last energy report was produced in 1998. Since that time, many improvements have been made to reduce the energy intensity of the iron and steel industry. After such a long interval, it is time for the industry to identify the techniques and practices that utilise the least energy whilst meeting increasing demands to reduce the industry’s impact on the environment from emissions.

This project utilised the expertise of a wide range of energy experts, member companies, universities and steel-related associations worldwide. It also involved worldsteel member plants and associations.

The aim was to identify the energy intensity of the industry now and to review the technologies in use. The data obtained is from practical applications with direct measurements. This approach revealed that some earlier theoretical calculations were optimistic. They didn’t always include the losses incurred in the process or were overly optimistic about the effectiveness of some of the proposed techniques.

During the discussions for this report it was decided to not use the All tech and Eco-tech plants developed in 1998. The energy intensity of these two reference plants was very strict and it was not possible for other metallurgical plants to reach this level. It is also not feasible to implement all of the Eco-tech technologies at all plants as some are difficult or impossible to retrofit. It is not economically feasible to abandon most existing facilities and replace them with new facilities incorporating the Eco-tech technologies.

The key difference between the 1998 report and this edition is the reliance on actual plant data and actual experiences with technology in operation. Every day, steelmakers are working with the energy saving technologies identified in this report. The information is not based on OEM data on the potential of a process or technology.

The reference plant values indicate that the top 25% of plants use 18 GJ of energy to produce a tonne of crude steel, and approximately 22 GJ to produce a tonne of hot rolled coil.

Table 10.1: Energy intensity results: worldsteel reference plant compared to energy project members

<table>
<thead>
<tr>
<th>Plant</th>
<th>Unit</th>
<th>worldsteel reference (Av. top 25% plants)</th>
<th>2010 (Average results)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke</td>
<td>MJ/t</td>
<td>5,719</td>
<td>5,540</td>
</tr>
<tr>
<td>Sinter plant</td>
<td>MJ/t</td>
<td>2,452</td>
<td>2,449</td>
</tr>
<tr>
<td>Pellet plant</td>
<td>MJ/t</td>
<td>1,700</td>
<td>1,185</td>
</tr>
<tr>
<td>DRI Gas</td>
<td>MJ/t</td>
<td>13,539</td>
<td>12,463</td>
</tr>
<tr>
<td>DRI Coal</td>
<td>MJ/t</td>
<td>15,316</td>
<td>N/A</td>
</tr>
<tr>
<td>Smelting reduction</td>
<td>MJ/t</td>
<td>21,497</td>
<td>-</td>
</tr>
<tr>
<td>BOF</td>
<td>MJ/t</td>
<td>17,677</td>
<td>16,744</td>
</tr>
<tr>
<td>BF</td>
<td>MJ/t</td>
<td>18,283</td>
<td>18,043</td>
</tr>
<tr>
<td>EAF (100% scrap)</td>
<td>MJ/t</td>
<td>6,762</td>
<td>5,656</td>
</tr>
<tr>
<td>EAF (iron ore based)</td>
<td>MJ/t</td>
<td>16,178</td>
<td>16,214</td>
</tr>
<tr>
<td>HRM (BOF)</td>
<td>MJ/t</td>
<td>20,365</td>
<td>20,225</td>
</tr>
<tr>
<td>HRM (EAF)</td>
<td>MJ/t</td>
<td>9,089</td>
<td>N/A</td>
</tr>
<tr>
<td>CSM (BOF)</td>
<td>MJ/t</td>
<td>19,945</td>
<td>17,674</td>
</tr>
</tbody>
</table>
A comprehensive worldsteel methodology was developed to analyse the energy intensity of the main metallurgical processes from raw materials to hot rolled coil. Energy specialists within member companies or other organisations can take an advantage of this methodology and process to analyse the energy intensity of metallurgical processes and integrated works.

Project members decided to establish a reference plant with realistic energy intensity. Matching the energy intensity of this new worldsteel reference plant is achievable without large capital investments with long payback periods as it is based on actual data from operating plants.

An energy data collection system (EDCS) was developed for confidential and secure data storage and simple analyses. The system was developed in four languages (English, Chinese, French and Russian). Participants can simply enter their energy performance data and find the gaps between the performance of their individual facilities and the reference plant. This helps them to identify where and how they can save energy at their plants and sites.

Members of worldsteel can enter data in the EDCS for different years, enabling them to analyse their energy intensity. The effect of investments in processes or modifications of operational activities can be measured without the need to physically implement these changes. The reference plant energy intensity values will be reviewed every three years and corrected on the basis of new information from member companies. The system is only available to member of worldsteel who have contributed to the project.

Forty-four energy surveys were submitted to the EDCS. The energy intensity of these sites was compared with the energy intensity of the new worldsteel reference plant. The potential energy saving for each analysed plant and site was calculated.

### 10.1 Project accomplishments

This project has identified how widely the technologies identified in the 1998 report and other literature, have been adopted across the steel industry.

The project has delivered a web-based benchmarking tool that:

- Ranks the performance of an analysed site against a reference plant
- Ranks individual plants against a reference plant
• Provides a means to compare the performance of each site in detail (waterfall charts) for a detailed breakdown of the gap
• Identifies the impact of raw material selection and quality on energy performance and shows the options available.

The database allows each site to identify what impact a technology, practice, or raw material type may have on energy consumption using real-time data from existing operations.

The project has delivered a report that describes the improvement potential of the world steel industry. It is based on actual data and experience rather than theoretic possibilities or supplier hopes.

A list of energy efficient technologies was developed. The list contains more than 190 technologies with information about those that are utilised most often.

Of the technologies identified in the 1998 report, 16.3% (17 out of 104 technologies) were not implemented within the sites studied for this report. Of the technologies identified from different sources, 9.2% of technologies (8 out of 87 technologies) were not implemented.

In total, 13% (25 out of 191 identified technologies) were not implemented yet. In the future, these technologies can play an important role in identifying opportunities for further energy savings in metallurgical processes.
11. Recommendations for steel producers

The energy intensity of steel production is complex. Steel producers must manage many variables to optimise energy use.

Energy represents between 20 and 25% of the total cost of steel production worldwide (depending on the local cost of energy).

The key recommendations from this report are:

- Undertake an energy analysis using the worldsteel model for each of the organisation’s sites and facilities.
- Use recycled scrap to the maximum economically feasible limit.
- Transfer best practices and apply technologies that suit your business.
- Demand improvements in raw material quality, balancing the economic cost against the organisation’s energy and process efficiency.
- Forecast the value of your changes. The worldsteel system can potentially translate energy intensity or savings to costs per tonne of product.

For more background to these recommendations, see Section 8: Energy Saving Potential of the Steel Industry.

Energy specialists worldwide agree on the following philosophy:

**Measure - Evaluate - Take action**

There is no single solution for metallurgical sites to decrease their energy intensity. The first step is to measure the current operation and its performance.

Without a standardised methodology, process and system, it is difficult to objectively evaluate the current situation. It is nearly impossible to forecast the impact of investing in technologies or practices at a specific site.

Capital and energy saving investments should not be made without a deep process analysis. It is not effective and may not generate the expected performance or savings. Implementing 25 to 30% of the energy saving technologies on the worldsteel list is generally enough to reach worldsteel reference energy intensity levels. However, they are only effective if the technologies, processes or improvements are operated in a diligent, disciplined manner.

Management of these plants must use sound decision-making principles based on objectively acquired facts and data. This enables them to obtain a high-level of reliability, low maintenance, and improve process and product yield.

This project has created a methodology and process and a well-tested model to compare energy intensity with the worldsteel reference and other sites. The methodology and process is available to anyone in the industry including research institutes. In the future it may even be developed into an international standard if sponsored by an ISO country.

Only worldsteel members can use the system now. It is accessed via a secure server. Access can be obtained by nominating a person to worldsteel who will allocate an ID for the site.

Figure 11.1 shows the five-steps required to improve the energy efficiency of steel production.
Recommendations for steel producers

1st Step: Effective management and operation decisions

2nd Step: Yield improvement

3rd Step: Maintenance

4th Step: Raw materials quality improvement

5th Step: Energy saving tech. implementation

Figure 11.1: Five steps to more energy efficient steel production
12. **List of appendices**

The appendices are available to worldsteel members from the Extranet or on CD.

- A  Confidentiality agreement
- B  Reference plant values
- C  Case studies
- D  List of energy saving technologies
- E  Definitions book
- F  List of checkpoints in the energy use methodology
- G  User guide for the energy use methodology – Excel file
- H  Short description of energy use web-based tool
- I  1998 energy report results and analyses
### 13. List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>alternating current</td>
</tr>
<tr>
<td>ARP</td>
<td>achievable reference plant</td>
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<tr>
<td>ASU</td>
<td>air separation unit</td>
</tr>
<tr>
<td>BF</td>
<td>blast furnace</td>
</tr>
<tr>
<td>BF/BOF plant</td>
<td>blast furnace and basic oxygen furnace process route (iron-ore based steel production)</td>
</tr>
<tr>
<td>BFG</td>
<td>blast furnace gas</td>
</tr>
<tr>
<td>BOF</td>
<td>basic oxygen furnace</td>
</tr>
<tr>
<td>BOFG</td>
<td>basic oxygen furnace gas</td>
</tr>
<tr>
<td>capex</td>
<td>capital expenditure</td>
</tr>
<tr>
<td>CCF</td>
<td>cyclone convertor furnace (HIsarna technology)</td>
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<tr>
<td>CCS</td>
<td>carbon capture and sequestration</td>
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<tr>
<td>CDQ</td>
<td>coke dry quenching</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined Heat and Power</td>
</tr>
<tr>
<td>CISRI</td>
<td>Chinese Iron and Steel Research Institute</td>
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<tr>
<td>CMC</td>
<td>coal moisture control</td>
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<td>COG</td>
<td>coke oven gas</td>
</tr>
<tr>
<td>CRC</td>
<td>cold rolled coil</td>
</tr>
<tr>
<td>CS</td>
<td>crude steel</td>
</tr>
<tr>
<td>CSR</td>
<td>coke strength after reaction</td>
</tr>
<tr>
<td>CV</td>
<td>calorific value</td>
</tr>
<tr>
<td>CWQ</td>
<td>coke wet quenching</td>
</tr>
<tr>
<td>DC</td>
<td>direct current</td>
</tr>
<tr>
<td>DRI</td>
<td>direct reduced iron</td>
</tr>
<tr>
<td>EAF</td>
<td>electric arc furnace (scrap-based steel production)</td>
</tr>
<tr>
<td>EDCS</td>
<td>energy data collection system</td>
</tr>
<tr>
<td>EI</td>
<td>energy intensity</td>
</tr>
<tr>
<td>EJ</td>
<td>exajoules (= 1018 joules)</td>
</tr>
<tr>
<td>ESP</td>
<td>energy saving potential</td>
</tr>
<tr>
<td>EST</td>
<td>energy saving technologies</td>
</tr>
<tr>
<td>ETS</td>
<td>Emissions Trading Scheme (European Union)</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EU-ETS</td>
<td>European Union Emissions Trading Scheme</td>
</tr>
<tr>
<td>FYP</td>
<td>five-year plan (China)</td>
</tr>
<tr>
<td>GDP</td>
<td>gross domestic product</td>
</tr>
<tr>
<td>GHG</td>
<td>greenhouse gases</td>
</tr>
<tr>
<td>GJ</td>
<td>gigajoule (= 109 joules)</td>
</tr>
<tr>
<td>GOX</td>
<td>gaseous oxygen</td>
</tr>
<tr>
<td>HBI</td>
<td>hot briquetted iron</td>
</tr>
<tr>
<td>HCDR</td>
<td>hot charge direct rolling</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>---------</td>
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</tr>
<tr>
<td>HCR</td>
<td>hot charge rolling</td>
</tr>
<tr>
<td>HDR</td>
<td>hot direct rolling</td>
</tr>
<tr>
<td>HM</td>
<td>hot metal</td>
</tr>
<tr>
<td>HP</td>
<td>high pressure</td>
</tr>
<tr>
<td>HRC</td>
<td>hot rolled coil</td>
</tr>
<tr>
<td>HSM</td>
<td>hot strip mill</td>
</tr>
<tr>
<td>IEA</td>
<td>International Energy Agency</td>
</tr>
<tr>
<td>IISI</td>
<td>International Iron and Steel Institute (name of worldsteel Association prior to 2008)</td>
</tr>
<tr>
<td>ITM</td>
<td>ion transport membrane</td>
</tr>
<tr>
<td>JCR</td>
<td>jumbo coke reacher</td>
</tr>
<tr>
<td>kgce/t</td>
<td>kilogram of coal equivalent per tonne</td>
</tr>
<tr>
<td>KPI</td>
<td>key performance indicator</td>
</tr>
<tr>
<td>kVA</td>
<td>kilovolt ampere</td>
</tr>
<tr>
<td>kWh</td>
<td>kilowatt hour</td>
</tr>
<tr>
<td>LNG</td>
<td>liquid natural gas</td>
</tr>
<tr>
<td>LP</td>
<td>low pressure</td>
</tr>
<tr>
<td>LPM</td>
<td>long product mill</td>
</tr>
<tr>
<td>m²</td>
<td>square metre</td>
</tr>
<tr>
<td>m³</td>
<td>cubic metre</td>
</tr>
<tr>
<td>MMBtu</td>
<td>million British thermal units</td>
</tr>
<tr>
<td>Mt</td>
<td>million metric tonnes</td>
</tr>
<tr>
<td>MW</td>
<td>megawatt</td>
</tr>
<tr>
<td>MWh</td>
<td>megawatt hour</td>
</tr>
<tr>
<td>NG</td>
<td>natural gas</td>
</tr>
<tr>
<td>Nm³</td>
<td>normal cubic metre</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Cooperation and Development</td>
</tr>
<tr>
<td>OHF</td>
<td>open hearth furnace</td>
</tr>
<tr>
<td>OTM</td>
<td>oxygen transport membrane</td>
</tr>
<tr>
<td>PCI</td>
<td>pulverized coal injection</td>
</tr>
<tr>
<td>PP</td>
<td>power plant</td>
</tr>
<tr>
<td>ppm</td>
<td>parts per million</td>
</tr>
<tr>
<td>PSA</td>
<td>pressure swing adsorption</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>research and development</td>
</tr>
<tr>
<td>RHF</td>
<td>rotary hearth furnace</td>
</tr>
<tr>
<td>SL/RN</td>
<td>Stelco Lurgi/Republic Steel DRI process</td>
</tr>
<tr>
<td>SR</td>
<td>smelting reduction</td>
</tr>
<tr>
<td>tCS</td>
<td>tonne of crude steel</td>
</tr>
<tr>
<td>TECO</td>
<td>worldsteel Technology Committee</td>
</tr>
<tr>
<td>tHMH</td>
<td>tonne of hot metal</td>
</tr>
<tr>
<td>tHRC</td>
<td>tonne hot rolled coil</td>
</tr>
<tr>
<td>TJ</td>
<td>terajoules (≈ 1012 joules)</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>tLS</td>
<td>tonne of liquid steel</td>
</tr>
<tr>
<td>TRT</td>
<td>top recovery turbine</td>
</tr>
<tr>
<td>TSR</td>
<td>thin slab rolling</td>
</tr>
<tr>
<td>ULCOS</td>
<td>Ultra Low Carbon Dioxide Steelmaking (project)</td>
</tr>
<tr>
<td>VSAP</td>
<td>vacuum swing adsorption process</td>
</tr>
<tr>
<td>VSD</td>
<td>variable speed driver</td>
</tr>
<tr>
<td>WHR</td>
<td>waste heat recovery</td>
</tr>
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