The State–of-the-Art Clean Technologies (SOACT) for Steelmaking Handbook

(2nd Edition)

Raw materials through Steelmaking, including Recycling Technologies, Common Systems, and General Energy Saving Measures

Asia Pacific Partnership for Clean Development and Climate

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Asia Pacific Partnership for Clean Development and Climate

Prepared for the Asia-Pacific Partnership on Clean Development and Climate,
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Introduction

The State–of-the-Art Clean Technologies (SOACT) for Steelmaking Handbook seeks to catalog the best available technologies and practices to save energy and reduce environmental impacts in the steel industry. Its purpose is to share information about commercialized or emerging technologies and practices that are currently available to increase energy efficiency and environmental performance between all the member countries in the Asia-Pacific Partnership on Clean Development and Climate.

Steel is used in many aspects of our lives, in such diverse applications as buildings, bridges, automobiles and trucks, food containers, and medical devices, to name a few. Steel provides substantial direct employment in the Asia-Pacific Partnership on Clean Development and Climate (APP) countries, and provides a significant direct contribution to the APP economies. Countless additional jobs and economic benefits are provided in steel industry supply and support activities, including mining, capital equipment supply, utilities and many community industries.

The aggregate carbon dioxide (CO_2) emissions from the global steel industry have reached roughly two billion tons annually, accounting for approximately 5% of global anthropogenic CO_2 emissions. Countries in the APP account for more than 57% of global steel production. The APP Steel Task Force, therefore, has significant potential to reduce CO_2 emissions and conserve energy by sharing information on clean technologies, and by cooperating to implement such technologies. To enable these efforts, the Partnership will emphasize public–private cooperation to reduce or remove barriers to technology implementation.

The production process for manufacturing steel is energy-intensive and requires a large amount of natural resources. Energy constitutes a significant portion of the cost of steel production, up to 40% in some countries. Thus, increasing energy efficiency is the most cost-effective way to improve the environmental performance of this industry.

To address these issues, there has been significant investment in new products, plants, technologies and operating practices. The result has been a dramatic improvement in the performance of steel products, and a related reduction in the consumption of energy and raw materials in their manufacture. Recent developments have enabled the steel industry's customers to improve their products through better corrosion resistance,

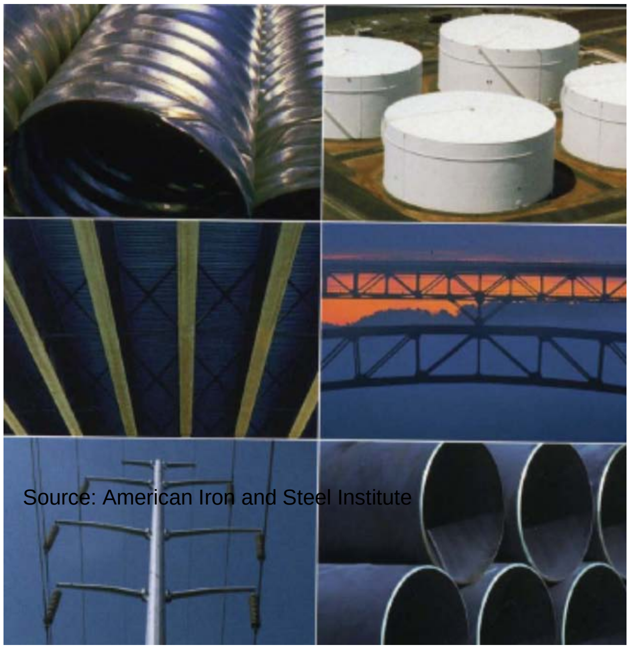


Figure 1: Some Steel Applications

reduced weight and improved energy performance. This improvement is seen through a wide range of products, including passenger cars, packaging and construction materials.

The steel industry is critical to the worldwide economy, providing the backbone for construction, transportation and manufacturing. In addition, steel has become the material of choice for a variety of consumer products, and markets for steel are expanding. Steel, already widely regarded as a high performance contemporary engineering material, is continuously being improved to meet new market demands. Globally, and in the APP countries, steel production is experiencing historic levels and continuing to grow. Figure 2 shows the expansion of crude steel production for APP countries and worldwide from 1980 to 2005.

Traditionally valued for its strength, steel has also become one of the most recycled materials. At the end of their useful life, products containing steel can be converted back into "new" steel, ready for other applications. Furthermore, the steel production process can utilize wastes and by-products as alternative reductants and raw materials, which reduces overall CO_2 emissions per ton of steel produced. In 2005, almost 43% of global crude steel production came from recycled steel. However, recycling rates vary significantly among products and countries.

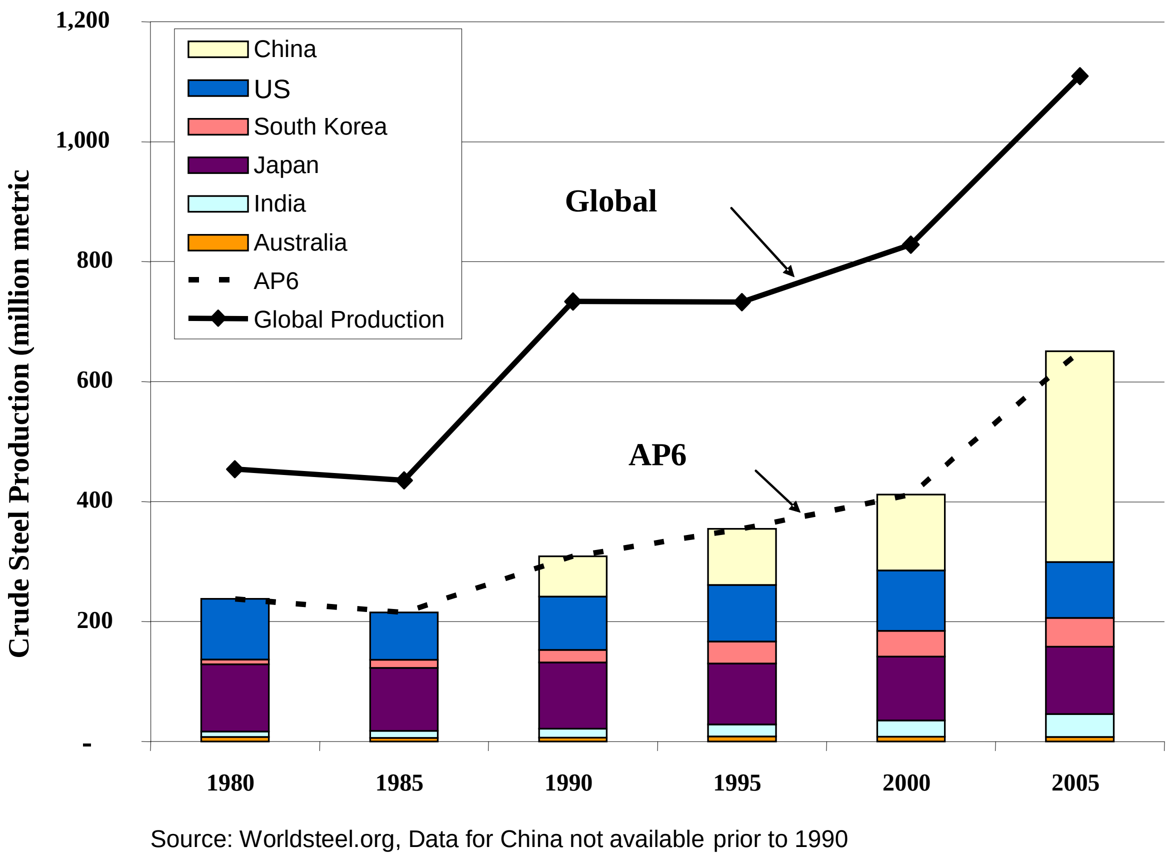


Figure 2: Steel production is growing in new and established markets

Steel Production Basics

Steel is an alloy consisting of iron, with a carbon content of between 0.02% and 2% by weight, and small amounts of alloying elements, such as manganese, molybdenum, chromium or nickel.

Steel has a wide range of properties that are largely determined by chemical composition (carbon and other alloys), controlled heating and cooling applied to it, and mechanical "working" of the steel in the finishing process.

The production of steel requires a number of steps, which can include:

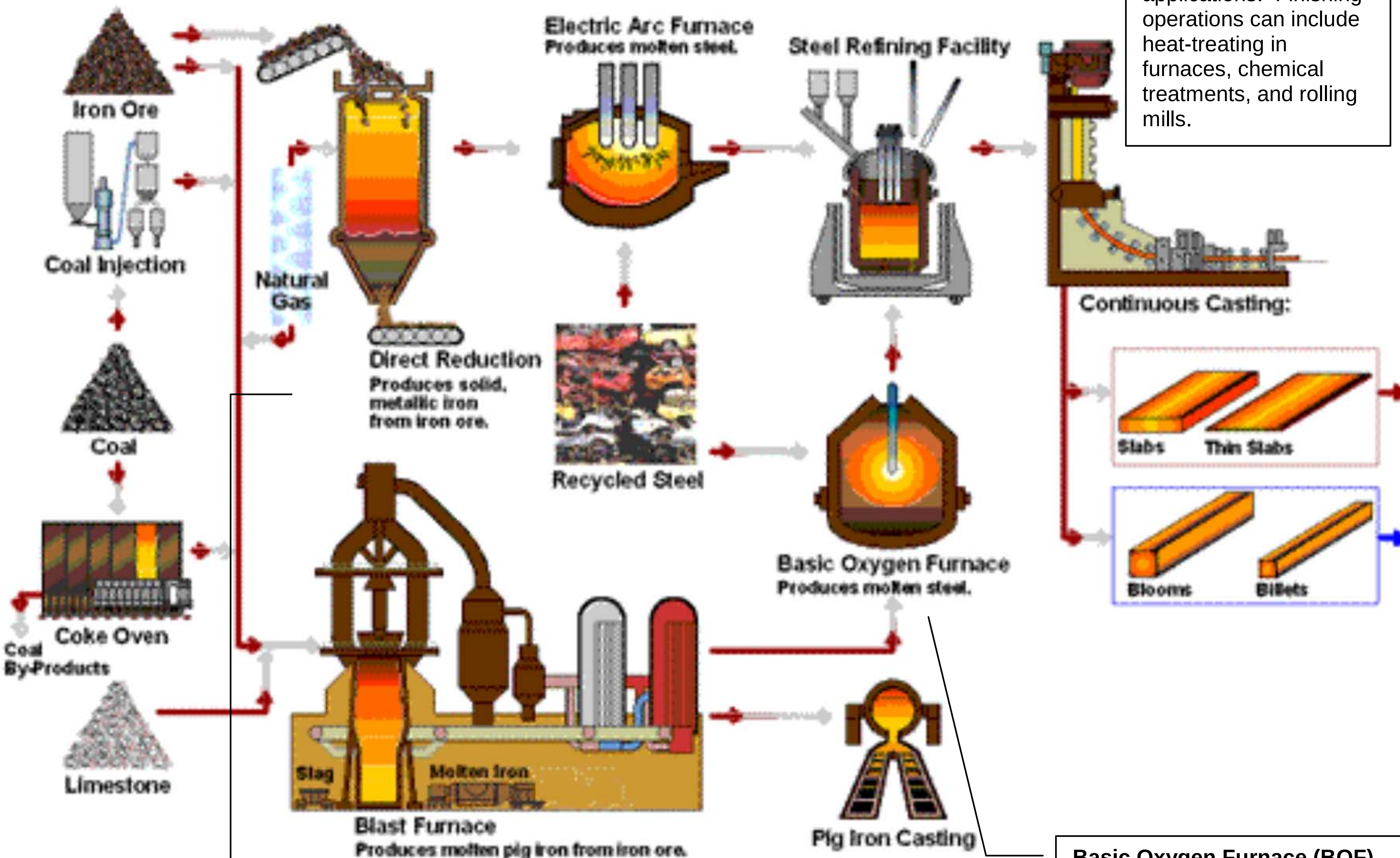
1. Agglomeration processes
   - 1.1 Sintering
   - 1.2 Pelletizing
   - 1.3 Briquetting
2. Cokemaking
3. Ironmaking by:
   - 3.1 Blast Furnace
   - 3.2 Direct Reduction
   - 3.3 Direct Ironmaking
4. Steelmaking by:
   - 4.1 Basic Oxygen Furnace (BOF) Steelmaking
   - 4.2 Electric Arc Furnace (EAF) Steelmaking
5. Ladle refining and casting
   - 5.1. Ladle Refining for BOF and EAF
   - 5.2. Casting
6. Rolling and Finishing
   - 6.1 Rolling and Forming
   - 6.2 Finishing

Source: http://www.stahl-online.de

Figure 3: Charging of a BOF

Steel production is a batch process. The two most common routes are a blast furnace in combination with a BOF, commonly referred to as "integrated" steelmaking, and a principally scrap based EAF, commonly referred to as the "minimill". Process steps associated with these two methods of steel production are illustrated in Figure 4.

Figure 4: Basic Flows of Steel Production



Electric Arc Furnace (EAF) Steelmaking: Molten iron and scrap are converted to steel by high-powered electric arcs.
Molten steel from the BOF or EAF is refined by the addition of alloys and is cast into solid forms for delivery to the finishing process.

Finishing: Steel is shaped into forms for varying industrial applications. Finishing operations can include heat-treating in furnaces, chemical treatments, and rolling mills.

Cokemaking: Coal is converted to coke for use in a blast furnace.

Ironmaking: Iron ore is reduced to iron in a blast furnace or direct reduction furnace.

Basic Oxygen Furnace (BOF) Steelmaking: Molten iron and scrap are converted to steel by the injection of oxygen.

1 Agglomeration

Materials preparation for ironmaking using a blast furnace involves two processes: iron ore preparation and cokemaking.

As a shaft furnace, a blast furnace requires the raw materials to form a permeable bed that will permit gases to pass through it. While lump iron ore can be used directly, iron ore *agglomerating processes* can improve the iron content and/or physical properties of the ore. Iron feed materials from such processes usually contain between 50% to 70% iron by weight.

The agglomeration processes are sintering, pelletizing and briquetting.

Source: Japan Iron and Steel Federation

Figure 5: Sinter Plant

1.1 Sintering

In sintering, iron ore fines, other iron-bearing wastes and coke dust are blended and combusted. The heat fuses the fines into coarse lumps that can be charged to a blast furnace. While sintering enables the use of iron ore fines, major issues are the large capital investment and the need for air pollution control strategies.

1.2 Pelletizing

In pelletizing, iron ore is crushed and ground to enable some of the impurities to be removed. The beneficiated (iron-rich) ore is mixed with a binding agent and then heated to create durable marble-sized pellets. These pellets can be used in both blast furnaces and direct reduction.

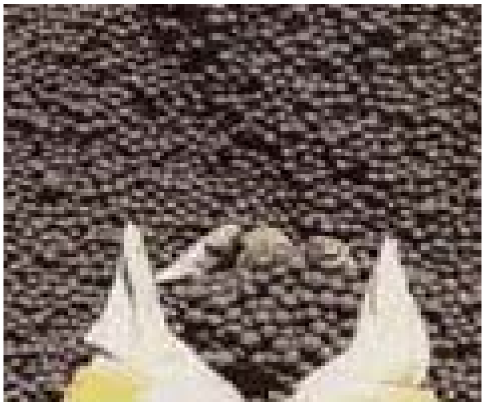


Figure 6: Pellets

1.3 Briquetting

In briquetting, crushed ore or fines are heated and compressed to produce briquettes.

2 Cokemaking

Coke is produced from metallurgical grade coals and is an essential part of integrated steelmaking, because it provides the carbon to remove the oxygen from iron ore and the heat to produce molten iron in the blast furnace. Due to its strength and porous nature, coke is an important contributor to the formation of the permeable bed required for the optimization of blast furnace performance. Cokemaking represents more than 50% of an integrated steelmaking's total energy use.

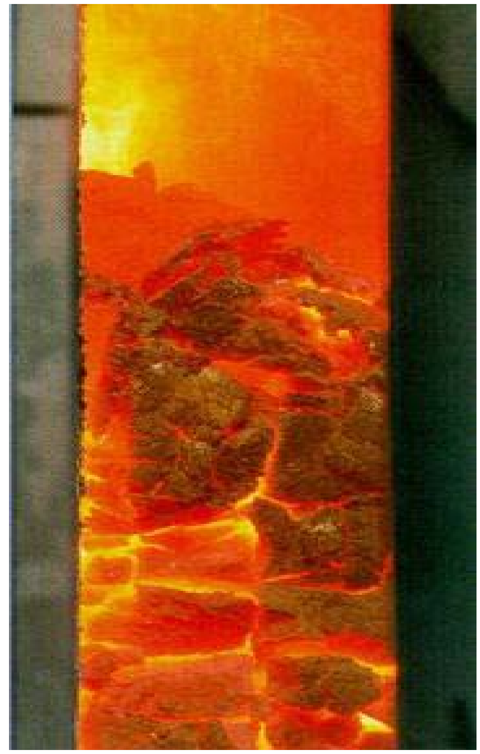


Figure 7: Incandescent coke in the oven

In the cokemaking process coal is heated in an oxygen-deficient atmosphere to drive off the hydrocarbon content of the coal, leaving the remaining carbon as the coke product. Coke production is achieved via a battery of large ovens consisting of vertical chambers separated by heating flues. In by-product cokemaking, the off-gases are collected and treated to be used as a fuel source for power generation, or supply process energy elsewhere in the steel production process, increasing overall energy efficiency. By-products from the gas may be further processed to recover chemicals that support other industries.
In non-recovery cokemaking, the hydrocarbon off-gases are combusted inside the oven to supply energy to the process and not recovered. The sensible heat in the gas may be recovered through waste heat boilers for power generation.

Major issues for cokemaking include availability of suitable coking coals, large capital investment and air pollution control strategies.

Figure 8: Hot coke being pushed from a Coke Oven Battery. The railroad car is full of incandescent coke.

3 Ironmaking

Ironmaking is the process of reducing iron ore (iron oxide as is commonly found in nature) into metallic iron through the removal of the oxygen. This conversion is the most energy-intensive stage of the steel process and has the potential to emit the largest CO2 emissions.

The most common method of producing iron – accounting for more than 90% of world iron production – involves the blast furnace, which is a shaft furnace containing a bed of iron ore as lump, sinter, pellets or briquettes, along with coke and a fluxing agent (usually limestone) that produces molten iron. The molten iron is commonly known as “pig iron”. The heat for the process comes from the burning of the coke using hot air that is passed through the bed. This burning of the carbon in the coke not only produces the heat to melt the iron, but also provides the reducing gas (mainly carbon monoxide (CO)) that strips the oxygen from the ore.

The other significant method of producing iron involves the direct reduction of iron ore using a reducing gas to produce direct reduced iron (i.e., with the bulk of its oxygen removed in a solid state). This iron is commonly known as “direct reduced iron” (DRI), and may be subsequently melted or made into briquettes.

There are a number of other methods of producing iron, which collectively are called “direct ironmaking” and are based on the desirability of using non-coking coals and avoiding the need to agglomerate the ore.

Figure 9: Iron from a blast furnace being poured into a torpedo car

3.1 Blast Furnace

The blast furnace is a tall cylindrical counter current shaft furnace lined with refractory brick. The iron ore feed material, along with coke and limestone, are charged into the top of the furnace. These materials pass down through the furnace in the opposite direction to the reduction gases. As the material moves downward, the oxygen content of the iron ore feed material is progressively removed by the reducing gases that are passing up through the bed. Heat and reducing gases are generated by the combustion of the coke with preheated air. This preheated air at around 1000-1200^{o}C is introduced into the lower region of the vessel through tuyeres. Molten iron and slag (which is a collection of the fluxing agent and the residual components from the iron ore and coke), collect in the bottom of the vessel and are tapped periodically. The iron produced from the blast furnace contains about 94% iron with greater than 4% carbon. The iron, as tapped, is too brittle for most engineering applications and therefore is further refined into steel.

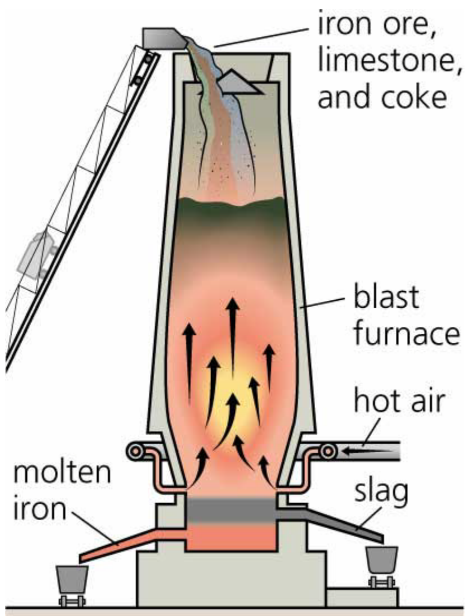


Figure 10: Blast Furnace

3.2 Direct Reduction

Direct reduction processes require a reducing gas to remove the oxygen from the iron containing material in a solid state. The reducing gas is in the form of CO and/or H_2. The majority of DRI in the world is produced in shaft furnaces, with natural gas as the feedstock for the reducing agent.

In shaft-based versions, which operate on a counter current basis like blast furnaces, the gas must be able to pass freely through the bed. Accordingly, pellets are the preferred iron ore feed material, with the iron ore feed material being charged into the top of the shaft. As with blast furnaces, this material passes down through the furnace in the opposite direction to the reduction gases, and as the material moves downward, the oxygen content of the iron ore feed material is progressively removed by the reducing gases that are passing up through the bed. Pre-heated reducing gases are introduced into the middle of the vessel. The reducing gases are created external to the shaft by preheating and reforming the reduction products coming from the top of the vessel using natural gas and/or coal. The pre-reduced solid iron is cooled and removed from the bottom of the shaft. An example of one shaft based process is shown below.

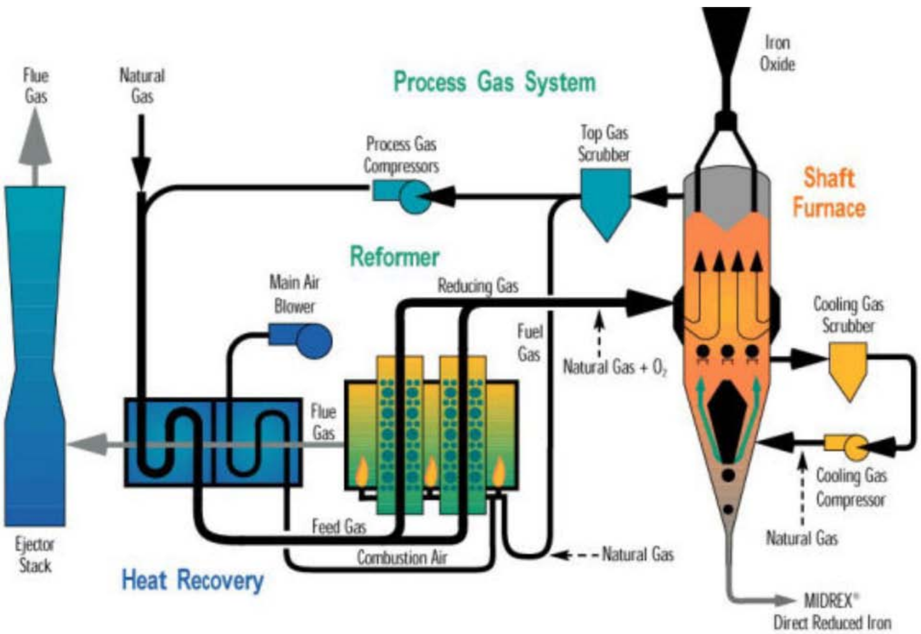


Figure 11. MIDREX Direct reduction processes

Direct reduction processes, given they are usually based on natural gas, can have lower emissions (including CO_2) than integrated plants that use coke ovens and blast furnaces. DRI is favored by electric arc furnace (EAF) steelmakers, who blend it as a feedstock with lower quality scrap to improve the steel quality. Direct reduction processes by their nature tend to be located near to readily available natural gas supplies, but often have higher fuel costs compared to coal/coke based processes. The amount of DRI that can be charged into an EAF is limited by any residue oxygen remaining, which increases steelmaking energy requirements. For good quality DRI the iron ore used must have low levels of impurities (gangue). Processed ores below 65% iron are usually considered unsuitable.

3.3 Direct Ironmaking

Concerns over limited long term supply of coking coals and the environmental impact of both coking and sinter plants have provided the drivers for the development of alternative ironmaking processes that use non-coking coals to reduce iron ores directly. These emerging direct ironmaking processes can be categorized by those producing molten iron (similar in quality to the blast furnace), and those producing a solid direct reduced iron.

3.3.1 Smelt Reduction Processes

The smelt reduction processes can be further differentiated by whether there is significant direct reduction occurring prior to producing the molten metal.

For those with direct reduction steps, like the Corex and Finex processes, the smelting reduction is achieved using counter current direct reduction in a shaft furnace in combination with a melter-gasifier. Here the gas for the direct reduction shaft furnace is created by feeding coal into a vessel that also receives hot DRI for melting. The coal is devolatilized by the heat in the furnace to produce a reduction gas of CO and H_2, and a bed of char. Oxygen is injected lower down into the vessel where it reacts with the char to produce heat and further CO. The heat from the combustion of the char melts the DRI and the molten metal collects in the hearth. The metal and slag are tapped periodically in the same manner as with a blast furnace operation.

In the direct smelting processes (i.e., those without a direct reduction step), like the HIsmelt, Ausiron and Romelt processes, all the feed materials are fed to a molten bath of metal and slag, where the iron ore feed materials are reduced to molten iron in a matter of seconds. The gases generated by the devolatilisation of the coal and reduction of the iron ore are combusted by using oxygen or oxygen enriched hot air, with the heat generated returned to the bath by the metal and slag layer.

3.3.2 Direct Reduction Processes

The direct reduction processes produce a solid product or direct reduced iron product from coal and iron ore fines or waste oxides. Technologies such as the Fastmelt and ITmk3 processes utilize a rotary hearth furnace.

4 Steelmaking

Steelmaking may be accomplished using either a Basic Oxygen Furnace or and Electric Arc Furnace. Both processes produce batches of steel known as "heats". In the basic oxygen process, molten iron with a carbon content of approximately 4.5 percent by weight is refined into steel with a carbon content between 0.02 percent to 2 percent by weight. In the EAF process a combination of scrap, DRI and pig iron may be processed to produce steel of similar composition.

4.1 Basic Oxygen Furnace (BOF) Steelmaking

The basic oxygen furnace (BOF) is charged with molten iron and scrap. The term "basic" refers to the magnesia (MgO) refractory lining of the furnace. Oxygen is injected through a water-cooled lance, resulting in a tremendous release of heat through the oxidation of carbon in the molten iron, with the CO providing vigorous mixing of the charge as it leaves the vessel. Aside from the oxygen, there is no fuel source needed to provide additional thermal energy. However, to maintain the auto-thermal process, the amount of scrap that can be charged is limited to about 30%. Steel is created when the carbon content of the iron charge is reduced from about 4% to less than about 2% (usually <1%).

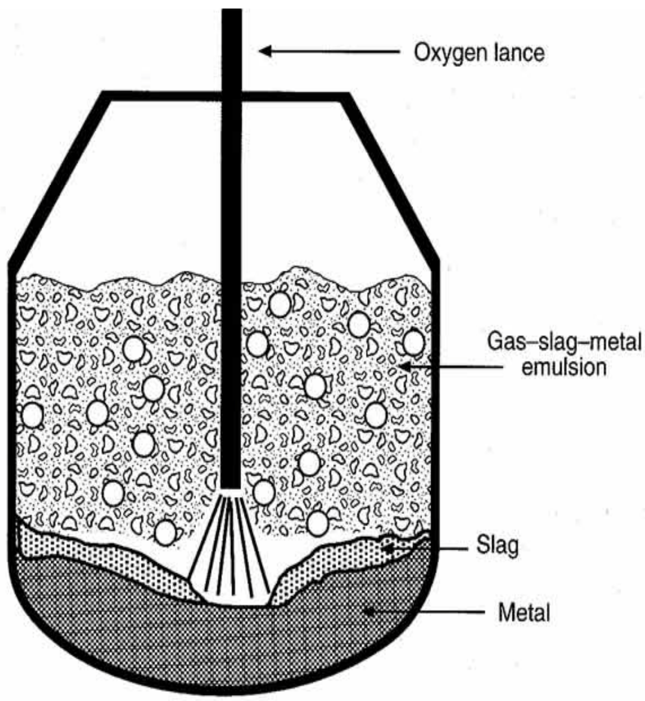


Figure 11: Basic Oxygen Furnace

After the molten steel is produced in the BOF and tapped into ladles, it may undergo further refining in a secondary refining process or be sent directly to the continuous caster, where it is solidified into semi-finished shapes: blooms, billets or slabs.

Table 1: Production of BOF Steel

	Production (million tonnes)
Australia	6.4
China	304.3
India	20.0
Japan	83.7
South Korea	26.7
USA	42.7
APP Total	483.9
Worldwide	738.8

Source: Worldsteel.org

BOF steelmaking represents about 75% of steel production in the APP countries. Of all BOF steel produced globally, APP countries produce about 65%. Table 1 compares the production of BOF steel in 2005 in the APP countries and worldwide.

4.2 Electric Arc Furnace (EAF) Steelmaking

Electric arc furnace (EAF) steelmaking uses heat supplied from the interaction of an arc of electricity between graphite electrodes and the metallic charge in the furnace to melt the solid iron feed materials. Although electricity provides most of the energy for EAF steelmaking, supplemental heating from oxy-fuel and oxygen injection is used.

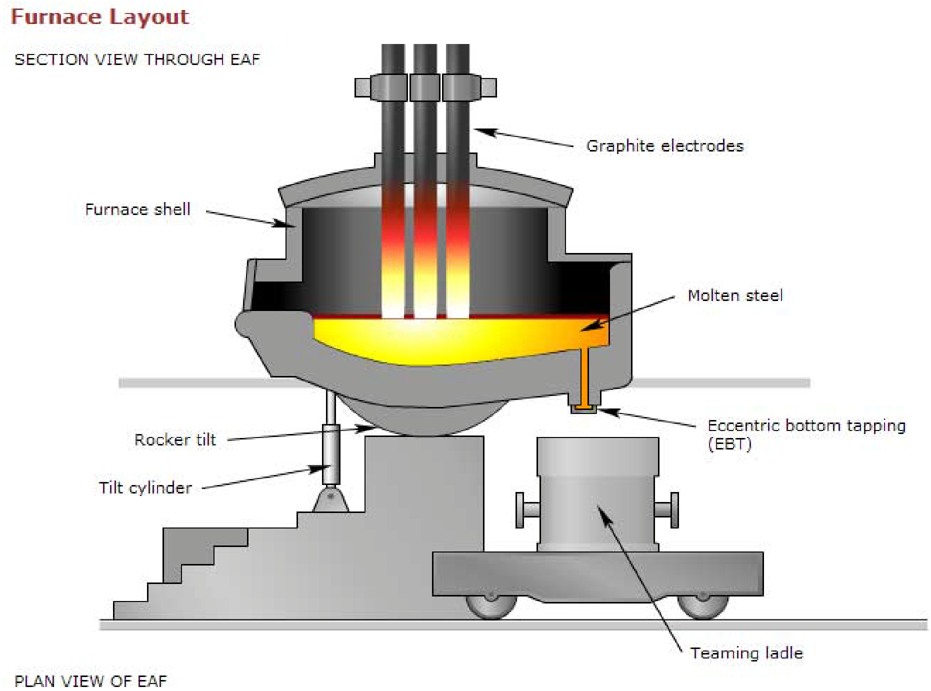


Figure 12: Electric Arc Furnace Diagram

The major advantage of EAF steelmaking is that it does not require molten iron supply. By eliminating the need for blast furnaces and associated plant processes like coke oven batteries, EAF technology has facilitated the proliferation of mini-mills, which can operate economically at a smaller scale than larger integrated steelmaking. EAF steelmaking can use a wide range of scrap types, as well as direct reduced iron (DRI) and molten iron (up to 30%). This recycling saves virgin raw materials and the energy required for converting them. Table 2 compares the production of EAF steel in 2005 in the APP countries and EAF production worldwide.

Table 2: Production of EAF Steel

	Production (million tonnes)
Australia	1.4
China	45.1
India	17.1
Japan	28.8
South Korea	21.1
USA	52.2
APP Total	165.6
Worldwide	358.1

Source: Worldsteel.org

The EAF operates as a batch melting process, producing heats of molten steel with tap-to-tap times for modern furnaces of less than 60 minutes.

EAF steelmaking represents about 25% of steel production in the APP countries. APP countries produce 46% of all EAF steel produced globally.

Current ongoing EAF steelmaking research includes reducing electricity requirement per ton of steel, modifying equipment and practices to minimize consumption of the graphite electrodes, and improving the quality and range of steel produced from low-quality scrap.

5 Ladle Refining and Casting

After the molten steel is produced in the BOF or EAF and tapped into ladles, it may undergo further refining or be sent directly to the continuous caster where it is solidified into semi-finished shapes: blooms, billets or slabs. The casting of near-net shapes saves energy during further downstream processing.

The undertaking of a ladle refining step prior to continuous casting can improve the efficiency of both the downstream casting and the upstream steelmaking steps. Continuous casting is most efficient when multiple ladles of a consistent steel grade can be fed through the caster. To do this, steps such as "trimming" the steel composition before casting are required. If such steps are undertaken outside of the BOF or EAF it reduces the overall tap-to-tap times of the BOF or EAF and thus maximizes their efficiency.

5.1 Ladle Refining for BOF and EAF

After steel is created in a BOF or EAF, it may be refined before being cast into a solid form. This process is called "ladle refining", "secondary refining" or "secondary metallurgy", and is performed in a separate ladle/furnace after being poured from the BOF or EAF.

Use of secondary refining has increased to meet precise product specifications

Figure 14: Ladle Metallurgy Furnace

Steel refining helps steelmakers meet steel specifications demanded by their customers. Refining processes include: chemical sampling; adjustments for carbon, sulfur, phosphor and alloys; vacuum degassing to remove dissolved gases; heating/cooling to specific temperatures; and inert gas injection to "stir" the molten steel.

5.2 Casting

Casting is the production of solid steel forms from molten steel.
Casting begins when refined steel is poured from a ladle into a tundish, which is a small basin at the top of the caster. An operator controls the flow of molten steel from the tundish. The falling steel passes through a mould and begins to take on its final shape. The strand of steel passes through the primary cooling zone, where it forms a solidified outer shell sufficiently strong enough to maintain the strand shape. The strand continues to be shaped and cooled as it curves into a horizontal orientation. After additional cooling, the strand is cut into long sections with a cutting torch or mechanical shears.

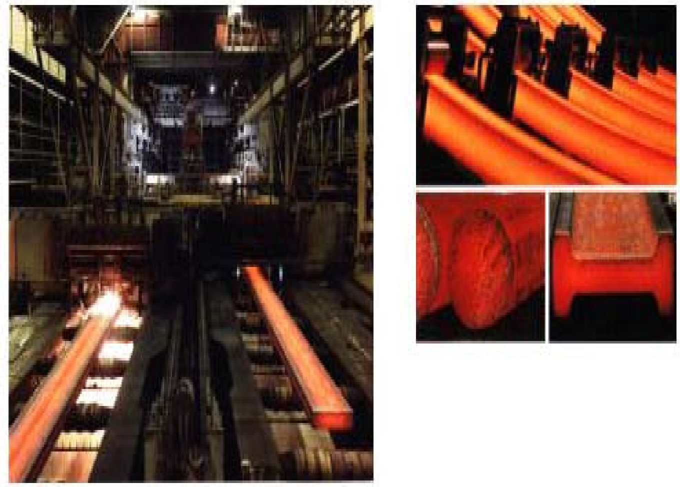


Figure 15: Continuous Casting: Molten steel is simultaneously cooled and formed into long strands of steel.

Historically, casting was performed by pouring steel into moulds in a batch process that produced large steel ingots. After cooling, the ingots were reheated prior to additional processing.

Continuous casting has replaced ingot casting at most steelmaking facilities because it produces large quantities of semi-finished steel closer to their final shape. The resulting steel forms often proceed directly to rolling or forming while retaining significant heat, which reduces downstream reheat costs. Continuous casting achieves dramatic improvements throughout, while reducing reheating and hot rolling costs.

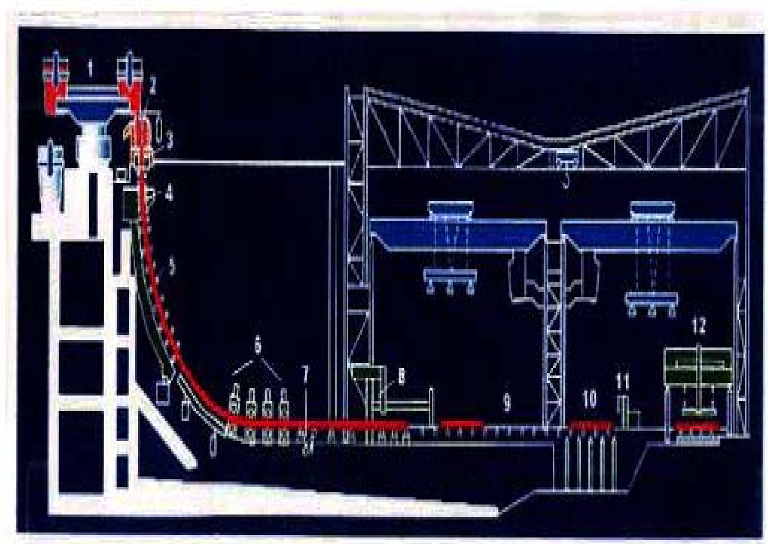


Figure 16: A schematic side view of a continuous caster

An emerging technology for the casting area is strip casting, which uses two rotating casting rolls to directly produce strip of less 2mm. This can reduce, or eliminate in some cases, further downstream processing requirements.

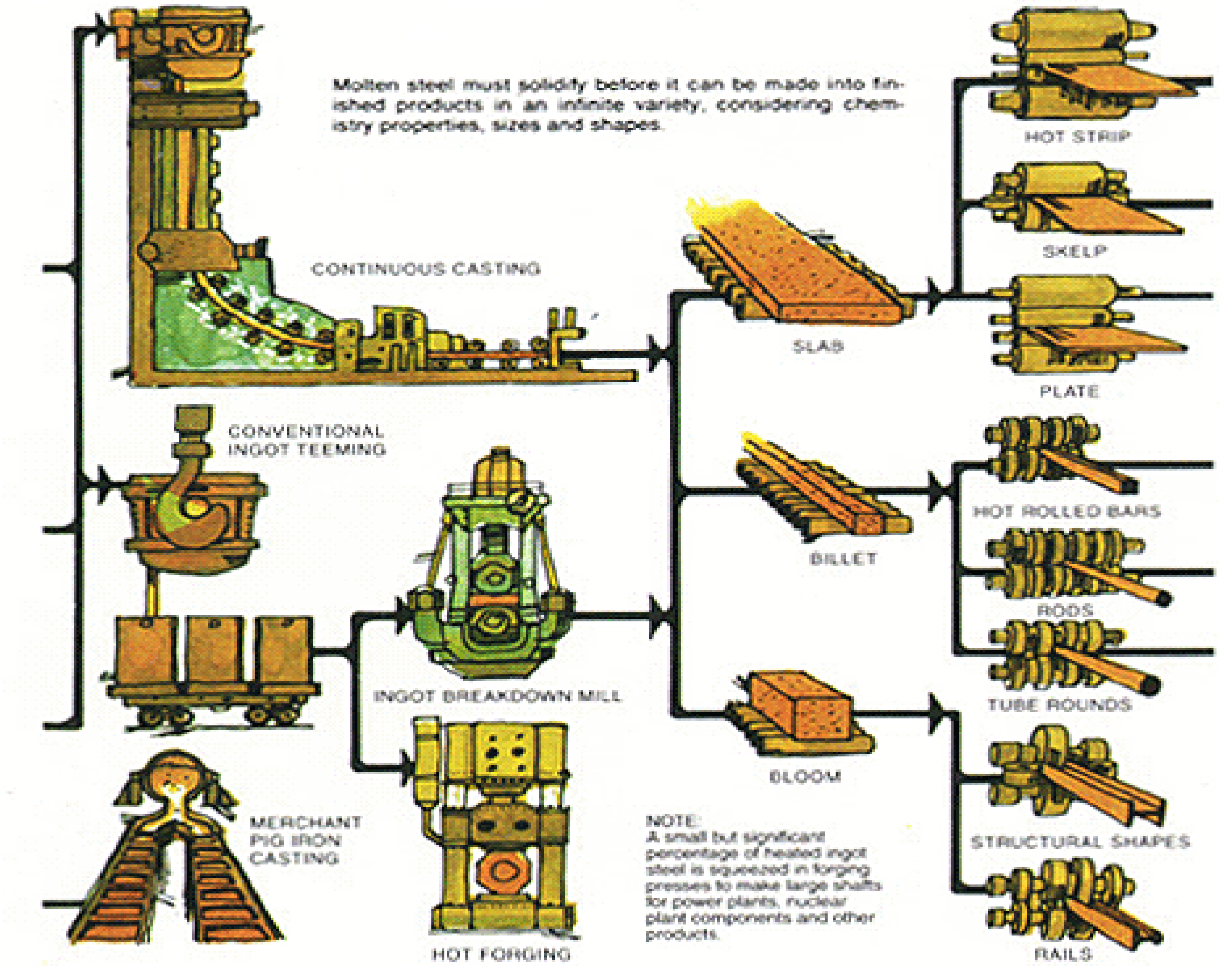


Figure 17: Types of Casting and Downstream Rolling

6 Rolling and Finishing

Rolling and finishing are the processes of transforming semi-finished shapes into finished steel products, which are used by downstream customers directly or to make further goods. Figure 18 summarizes the basic rolling and finishing processes.

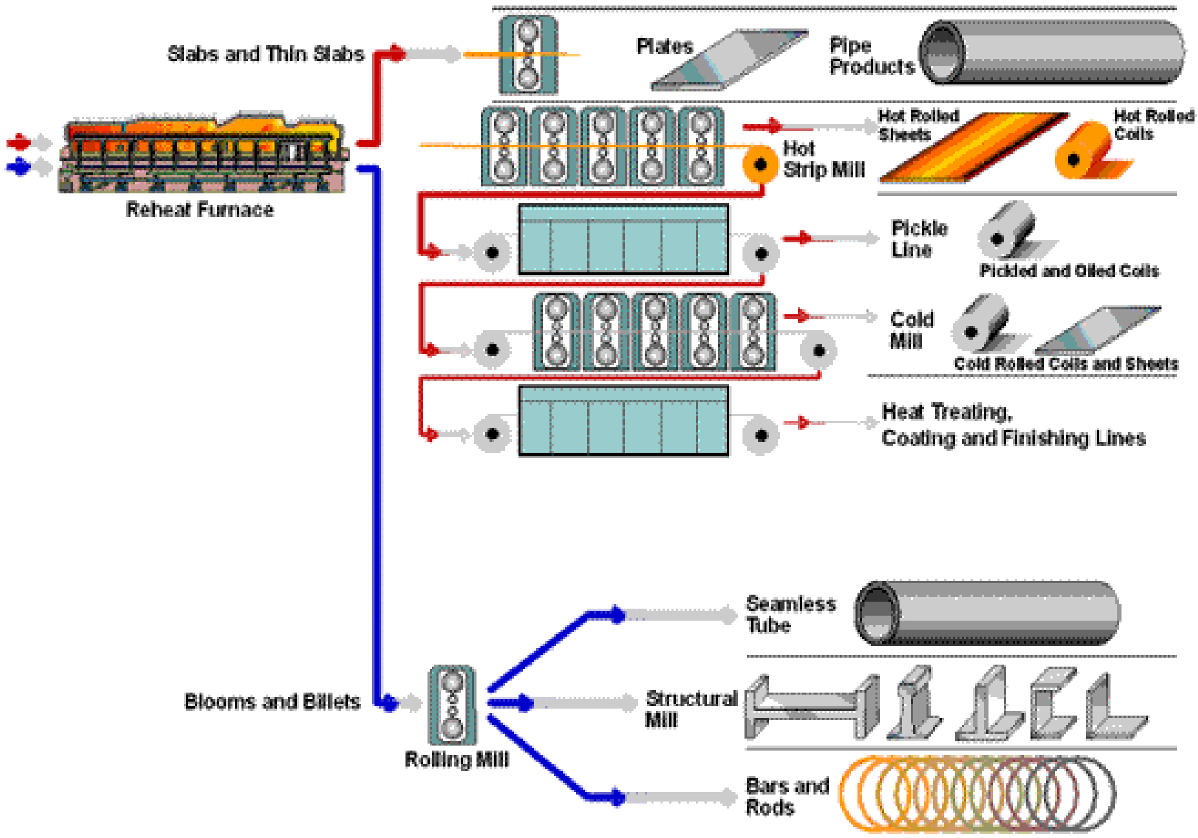
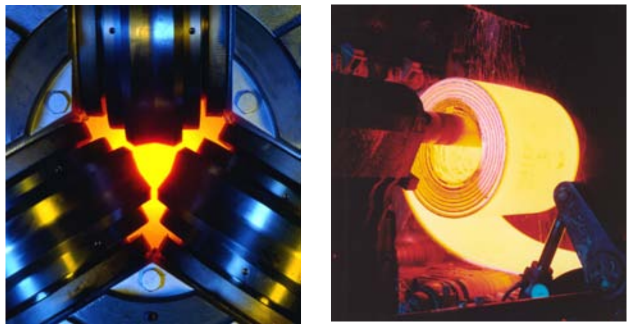


Figure 18: Examples of Steel Product Flowlines

Finishing processes can impart important product characteristics that include: final shape, surface finish, strength, hardness and flexibility, and corrosion resistance.
Current finishing technology research focuses on improving product quality, reducing production costs and reducing pollution.

6.1 Rolling and Forming

Rolling and forming semi-finished steel (slabs, blooms or billets) is the mechanical shaping of steel to achieve desired shape and mechanical properties.



Source: http://www.stahl-online.de

Figure 19: Rolling and Forming Processes

Operations can include hot rolling, cold rolling, forming or forging. In hot rolling of steel to strip, for example, steel slabs are heated to over 1,000^{o}C and passed between multiple sets of rollers. The high pressure reduces the thickness of the steel slab while increasing its width and length. After hot rolling, the steel may be cold-rolled at ambient temperatures to further reduce thickness, increase strength (through cold working), and improve surface finish. In forming, bars, rods, tubes, beams and rails are produced by passing heated steel through specially shaped rollers to produce the desired final shape. In forging, cast steel is compressed with hammers or die-presses to the desired shape, with a resultant increase in its strength and toughness.

6.2 Finishing

Finishing of steel is performed to meet specific physical and visual specifications.

Operations include pickling, coating, quenching and heat treatment. Pickling is a chemical treatment, in which rolled steel is cleaned in an acid bath to remove impurities, stains or scales prior to coating.

Figure 20: Vertical coating line

In coating, cold-rolled sheet steel is coated to provide protection against corrosion and to produce decorative surfaces. Strip coating lines are generally operated continuously, so that in the entry section an endless strip is produced which is divided into coils at the exit section. Coatings may be applied in a hot bath (often zinc-based), in an electro galvanizing bath, or in a bath containing liquid tin.

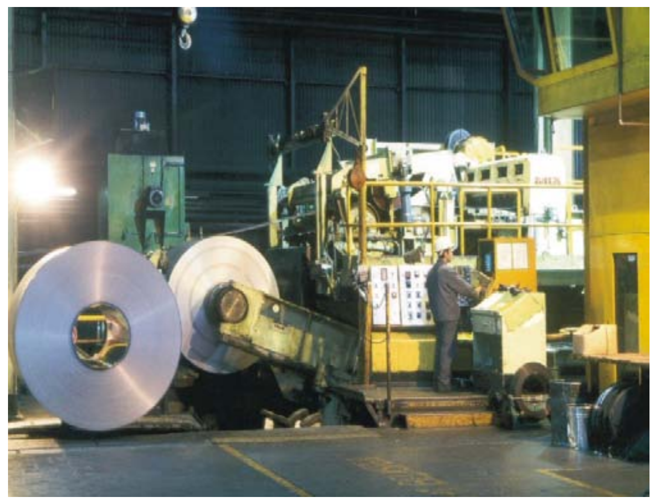


Figure 21: Galvanized (zinc-coated) steel

Quenching, the rapid cooling of steel, is often achieved using water or other liquids. Quenching can increase steel's hardness and is often combined with tempering to reduce brittleness.

The controlled heating and subsequent cooling of steel in heat treatment can impart a range of qualities upon the steel by altering its crystalline structure. Heat treatment is often performed after rolling to reduce the strain that occurs in rolling processes. Annealing, tempering and spheroidizing are three examples of heat treatment, which may be performed in a large batch furnace or in a continuous furnace under a controlled atmosphere (i.e., hydrogen).

Source: http://www.stahl-online.de

Figure 22: Heat treatment furnace

7 Recycling and Waste Reduction Technologies

Steel production uses large quantities of raw materials, energy and water, while millions of tonnes of steel products reach the end of their useful lives each year.

The steel industry is a recognized leader in developing recycling efforts that minimize the environmental footprint of steel production while reducing costs. Below are some examples in steel recycling, energy efficiency and generation, dust and solids reduction and reuse, and water and gas recycling.

Steel recycling
Steel is the world's most recycled material. In many countries, more than half of all old cars, cans and appliances are recycled. EAF steelmaking is based primarily on the use of scrap steel.

Energy
The use of scrap dramatically reduces energy intensity per tonne of steel produced. The use of combined heat and power (CHP) technology to burn off-gases from steelmaking produces on-site steam and electricity, reducing inefficiencies in generation off-site and distribution across long distances.

Dusts and solids
Coke dust (breeze), iron ore dust and other solids are processed and recycled in steel mills. Slag from ironmaking and steelmaking is used for road construction and aggregate.

Water and gases
Steelmakers recycle and reuse much of their water. Coke oven gas is recovered and refined for internal use (fuel) and external sales (tars, oils and ammonia). Blast furnace gas is recovered and used to provide heat to the ironmaking process.

Figure 23: Recycling of scrap steel and onsite power generation are an important part of modern steelmaking

8 Common Systems

Steel production requires the heating, shaping and movement of large quantities of materials, in addition to the steelmaking processes discussed previously. These large and essential common systems are described below.

Boilers
Almost all steam for steelmaking is produced in boilers. Steam is used for heating in the finishing process, space heating, and for machine drive. Boiler fuels include by-product gases (e.g., coke oven gas and blast furnace gas), as well as conventional fossil fuels.

Pumps
The large quantities of cooling water and liquids used in steelmaking require large pumps. Pumping systems require large drives and sophisticated maintenance systems.

Figure 24: Ancillary Equipment

Motors
Steelmakers use some of the largest motors in the industrial sector. Electric motors are used in blast furnace fans, rolling mills and numerous other operations. Maintaining motors and minimizing power consumption is a priority for the industry.

Compressed Air
Many control systems and small drives use compressed air. Compressed air systems demand rigorous maintenance to assure efficiency and reliability.

9 General Energy Savings & Environmental Measures

Steel production uses large quantities of raw materials, energy and water. As with any industry, these need to be managed well in order to maximize productivity and profits. As such, improving energy and resource efficiency should be approached from several directions. A strong corporate-wide energy and resource management program is essential. While process technologies described in sections 1 through 8 present well-documented opportunities for improvement, equally important is fine-tuning the production process, sometimes producing even greater savings. In section 9 are some measures concerning these and other general crosscutting utilities that apply to this industry, such as energy monitoring and management systems, cogeneration applications, preventive maintenance practices, slag uses and carbonation processes, and hydrogen production.

Figure 25: Gas Turbine Systems

State-of-the-Art Clean Technologies

1 Agglomeration

1.1 Sintering

1.1.1 Sinter Plant Heat Recovery

Description:
Heat recovery at the sinter plant is a means for improving the efficiency of sinter making. The recovered heat can be used to preheat the combustion air for the burners and to generate high-pressure steam, which can be run through electricity turbines. Various systems exist for new sinter plants (e.g. Lurgi Emission Optimized Sintering (EOS) process) and existing plants can be retrofit[1,2].

Energy/Environment/Cost/Other Benefits:

- Retrofitted system at Hoogovens in the Netherlands:
  - Fuel savings in steam and coke achieved
  - NOx, SOx and particulate emissions reduced
  - Capital costs of approximately $3/t sinter[1]
- Wakayama Sintering Plant trial operation in Japan:
  - 110-130 kg/t of sinter recovered in steam
  - 3-4% reduction in coke
  - 3-10% reduction in SOx
  - 3-8% reduction in NOx
  - About 30% reduction in dust
  - Increased productivity, yield, and cold strength
- Taiyuan Steel in Japan:
  - Recovered exhaust heat equaled 15 t/h (or 12,000 KL/year crude oil)
  - SO_2 reduced
- NEDO reports the energy saving of 4700 GJ/year for a 100 Mton-sinter/year plant (47 kJ/tonne sinter)[3]

Block Diagram or Photo:

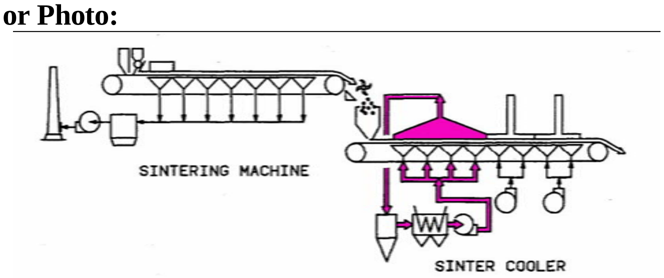


Figure 1.1: Sinter plant heat recovery from sinter cooler [1]

Commercial Status: Mature
Contact information: Sumitomo Metal Industries, Ltd. http://www.sumitomometals.co.jp

[1] Farla, J.C.M., E. Worrell, L. Hein, and K. Blok, 1998. Actual Implementation of Energy Conservation Measures in the Manufacturing Industry 1980-1994, The Netherlands: Dept. of Science, Technology & Society, Utrecht University.
[2] Stelco, 1993. Present and Future Use of Energy in the Canadian Steel Industry, Ottawa, Canada: CANMET.
[3] NEDO (New Energy and Industrial Technology Development Organization, Japan), 2008. *Global Warming Countermeasures: Japanese Technologies for Energy Savings/GHG Emissions Reduction (2008 Revised Edition).* Available at: http://www.nedo.go.jp/library/globalwarming/ondan-e.pdf

1.1.2 District Heating Using Waste Heat

Description:
District heating using waste heat in the steel industry is a method for not only saving energy, but also for sharing resources with nearby residential and commercial buildings.

Energy/Environment/Cost/Other Benefits:
- District heating of 5,000 houses, 800 TJ/year using sinter cooler waste heat
- Fossil energies such as LPG/LNG are substituted
- Investment $22.3 million

Block Diagram or Photo:

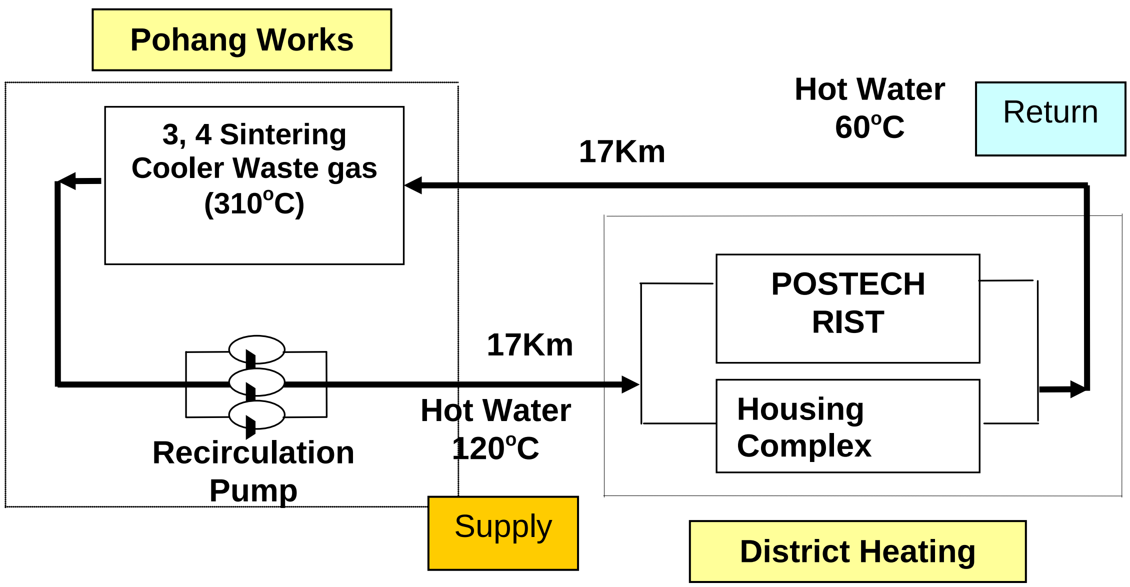


Figure 1.2: Flow diagram of Pohang Steelworks district heating system

Commercial Status: Mature

Contact information:
Yun Sik Jung, Environmental & Energy Dept., POSCO
http://www.posco.co.kr

1.1.3 Dust Emissions Control

Description:
Production increase leads to increased dust generation, thereby increasing particulate emissions. These emissions - off/waste gas – are dust-laden, containing a wide variety of organic and heavy metal hazardous air pollutants (HAPs). Total HAPs released from individual sinter manufacturing operations may exceed ten tons per year[4]. By sending waste gas to Electrostactic Precipitators (ESPs) through negatively charged pipes, the particulate matter (PM) in the waste stream becomes negatively charge. Routing the stream past positively charged plates will then attract and collect the negatively charged PM, thereby producing clean waste gas and increasing the quantity of steam recovery. Course dusts are removed in dry dust catchers and recycled.

Energy/Environment/Cost/Other Benefits:

- Can achieve over 98% efficiency, reducing dust load in off-gas of a typical plant from 3,000 mg/m^3 to about 50 mg/m^3
- ESP removal of fine dust may reduce PM emission levels at sinter plants to about 50 – 150 mg/m^3 depending on actual Specific Dust Resistivity and/or sinter basicity
- ESPs can be installed at new and existing plants
- ESPs cause increased energy consumption of about 0.002 to 0.003 GJ/t sinter
- Kashima Steel Works in Japan installed ESP

Block Diagram or Photo:

Figure 1.3: A photo of an ESP

Commercial Status: Mature

Contact information:
Mitsubishi Heavy Industries Environment Engineering Co., Ltd

[4] P. J. Marsosudiro 1994. *Pollution Prevention in the Integrated Iron and Steel Industry and its Potential Role in MACT Standards Development,* 94-TA28.02. US Environmental Protection Agency.

1.1.4 Exhaust Gas Treatment through Denitrification, Desulfurization, and Activated Coke Packed Bed Absorption

Description:

Sintering exhaust gas contains SOx, NOx, dust and dioxins. These contaminants are processed, adsorbed, decomposed and/or collected as non-toxic by-products to increase the quantity of steam recovery, and improve total fuel savings. Treatment methods to achieve these include: (1) Denitrification Equipment, (2) Desulfurization Equipment, and (3) Activated Coke Packed Bed Adsorption.

Energy/Environment/Cost/Other Benefits:

- SOx is adsorbed and recovered as useful by-product
- NOx is decomposed to nitrogen, water and oxygen by ammonia
- Dust is collected in activated coke.
- Dioxins are collected or adsorbed in activated coke and decomposed at 450℃ with no-oxygen
- Removal efficiencies *: Up to 99.9% SOx, 50-80% NOx, High particulate removal, Dioxins <0.1 ng-TEQ/m3N, Above 90% mercury

Block Diagram or Photo *:

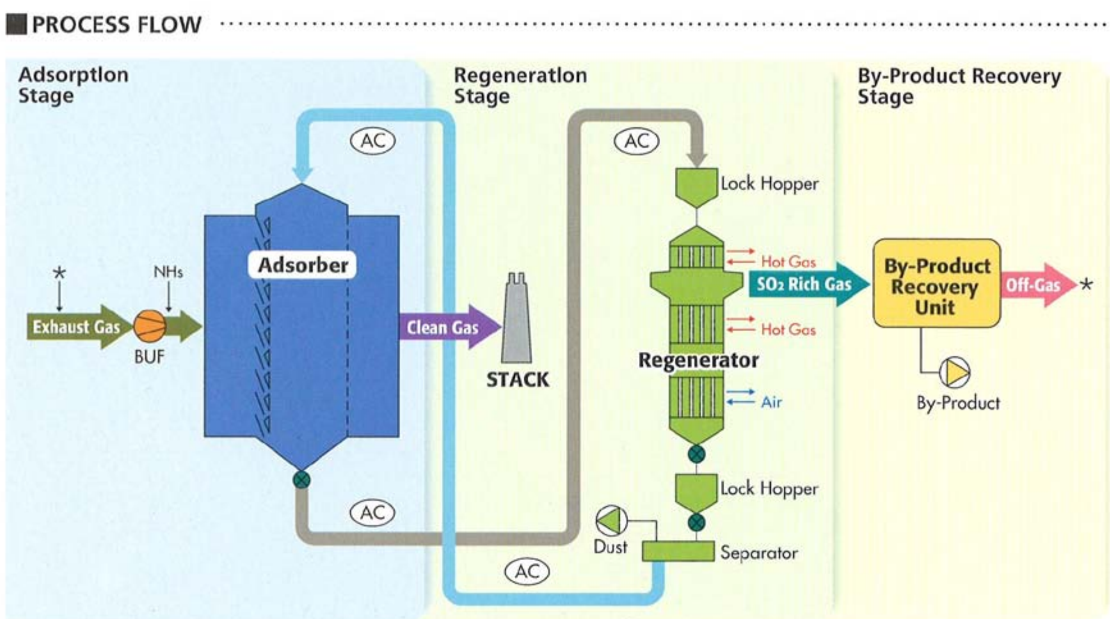


Figure 1.4: Process flow diagram of activated coke method

* Extracted from J-Power EnTech brochure. All rights reserved by J-Power EnTech.

Commercial Status: Mature

Contact information:

J-Power EnTech, Inc.
http://www.jpower.co.jp/entech_e/index.html

1.1.5 Exhaust Gas Treatment through Selective Catalytic Reduction

Description:

SOx and dioxins contained in the sinter flue gas are removed in this process by adding sodium bi-carbonate and Lignite.

NOx is removed by the selective catalytic reduction reaction at around 200~450°C:

$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$

For SOx removal the reactions are:

$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$ (T>140°C)

$Na_2CO_3 + 2SO_2 + 1/2O_2 \rightarrow Na_2SO_4 + 2CO_2$

Lignite Injection produces dioxin < 0.2 ng-TEQ/Nm^3.

Energy/Environment/Cost/Other Benefits:

- High SOx and NOx removal efficiency

Block Diagram or Photo:

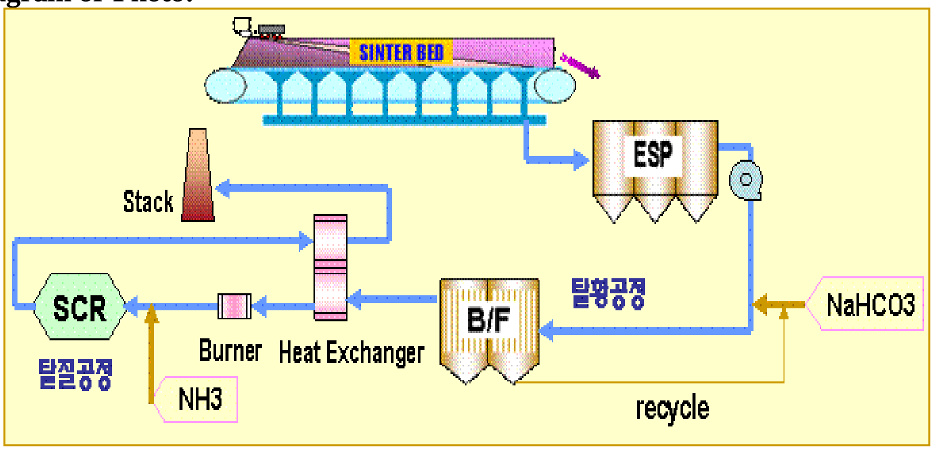


Figure 1.5: NOx and SOx removal using selective catalytic reduction

Commercial Status: Emerging

Contact information:

Mr. Youngdo Jang
Department of Environment & Energy, POSCO
Phone: +82-54-220-5773

Installation information:

Full-scale facility is being installed in Kwangyang Works; 4 units expected to be completed June 2007.

1.1.6 Exhaust Gas Treatment through Low-Temperature Plasma

Description:
Active radicals of low-temperature plasma remove SOx, NOx and HCl simultaneously. Dioxin also decreased with the addition of Lignite to the process. Reliability and stability have been proven (over five years of operation). Core technology includes full-scale magnetic pulse compressor, stabilizing pulse width and rising time, proper reactor capacity design, and energy saving technology through additives.

Energy/Environment/Cost/Other Benefits:
- Low cost with high pollutants removal efficiency
- Compact - less space required than other technologies
- A commercial scale plant installed at an incinerator in Kwang Works showed a substantial reduction of SOx(>70%), NOx(>95%) and HCl(>99%)
- Dioxin also decreased to less than 0.2 ng-TEQ/Nm3

Block Diagram or Photo:

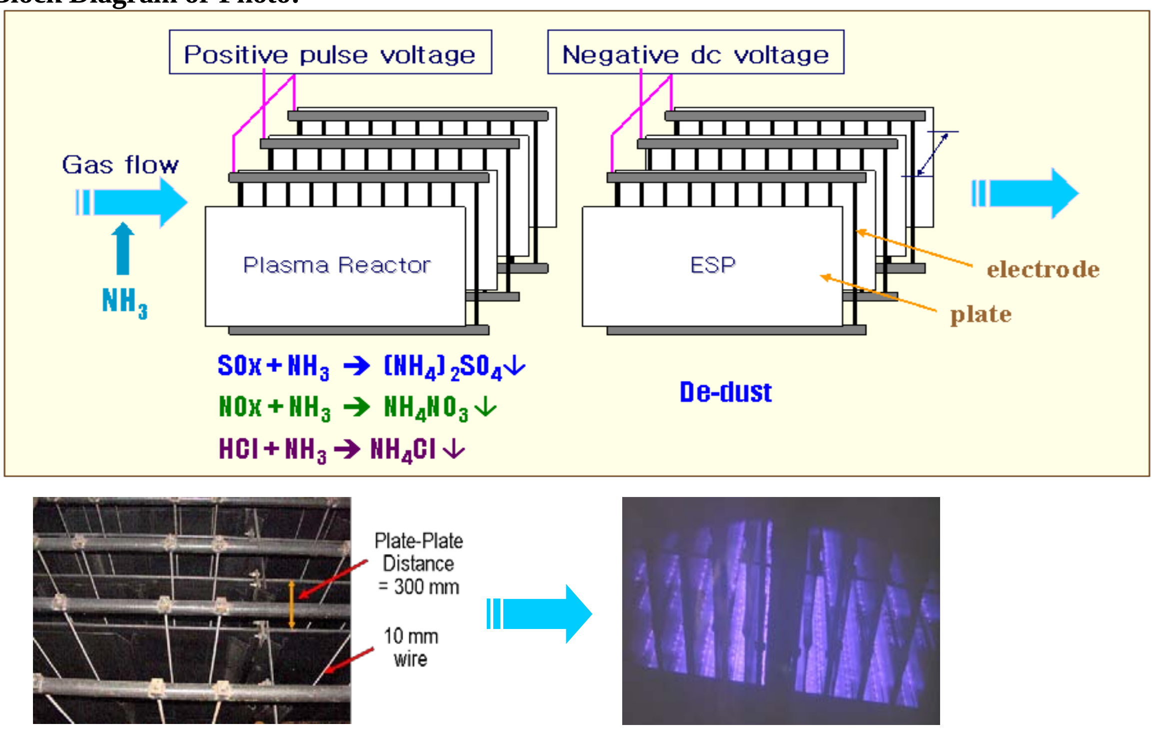


Figure 1.6: NOx and SOx removal using low-temperature plasma

Commercial Status: Emerging

Contact information:
Mr. Youngdo Jang, Department of Environment & Energy, POSCO
T +82-54-220-5773
ydjang@posco.co.kr

Installation information:
Installation of commercial scale plant in 2000 at Kwanyang Works
POSCO plans to adopt above technology at Sinter plant in Pohang Works in about 2010

1.1.7 Improvements in Feeding Equipment

Description:
An additional screen is installed on the conventional sloping chute, which promotes a more desirable distribution of granulated ore on the palette.

Energy/Environment/Cost/Other Benefits:
- The screen with a sloping chute places coarser granulated ore in the lower part of the palette and finer ore on the upper part, which achieves high permeability

Block Diagram or Photo:

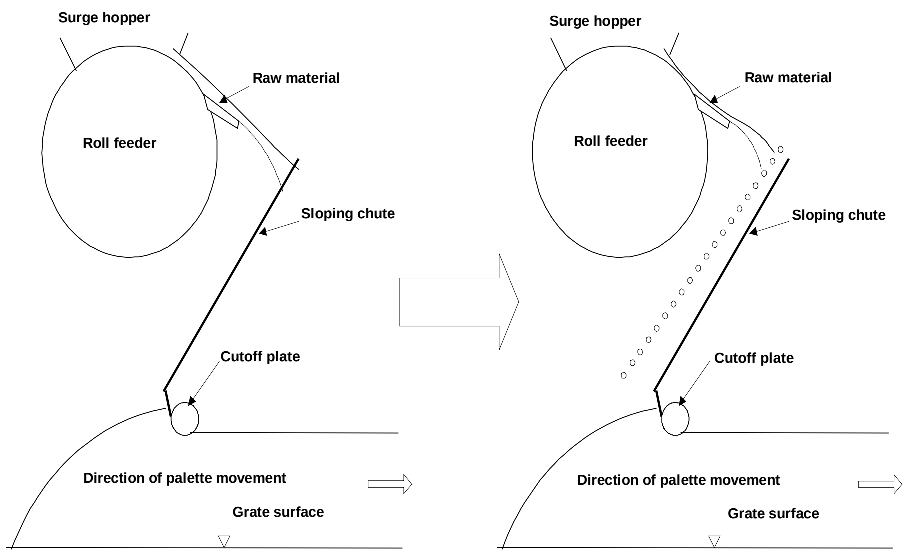


Figure 1.7: Outline of improvements in feeding equipment

Commercial Status: Mature

Contact information:
Sumitomo Metal Industries, Ltd.
http://www.sumitomometals.co.jp

1.1.8 Segregation of Raw Materials on Pellets

Description:
Segregation and granulation reinforcement of raw materials on sintering pellets improve permeability and decrease return rate to sintering pellets, thus increasing productivity and saving energy.

Energy/Environment/Cost/Other Benefits:
- Effective in improving permeability and decrease return rate to sintering pellets
- Increases productivity and saves energy

Block Diagram or Photo:

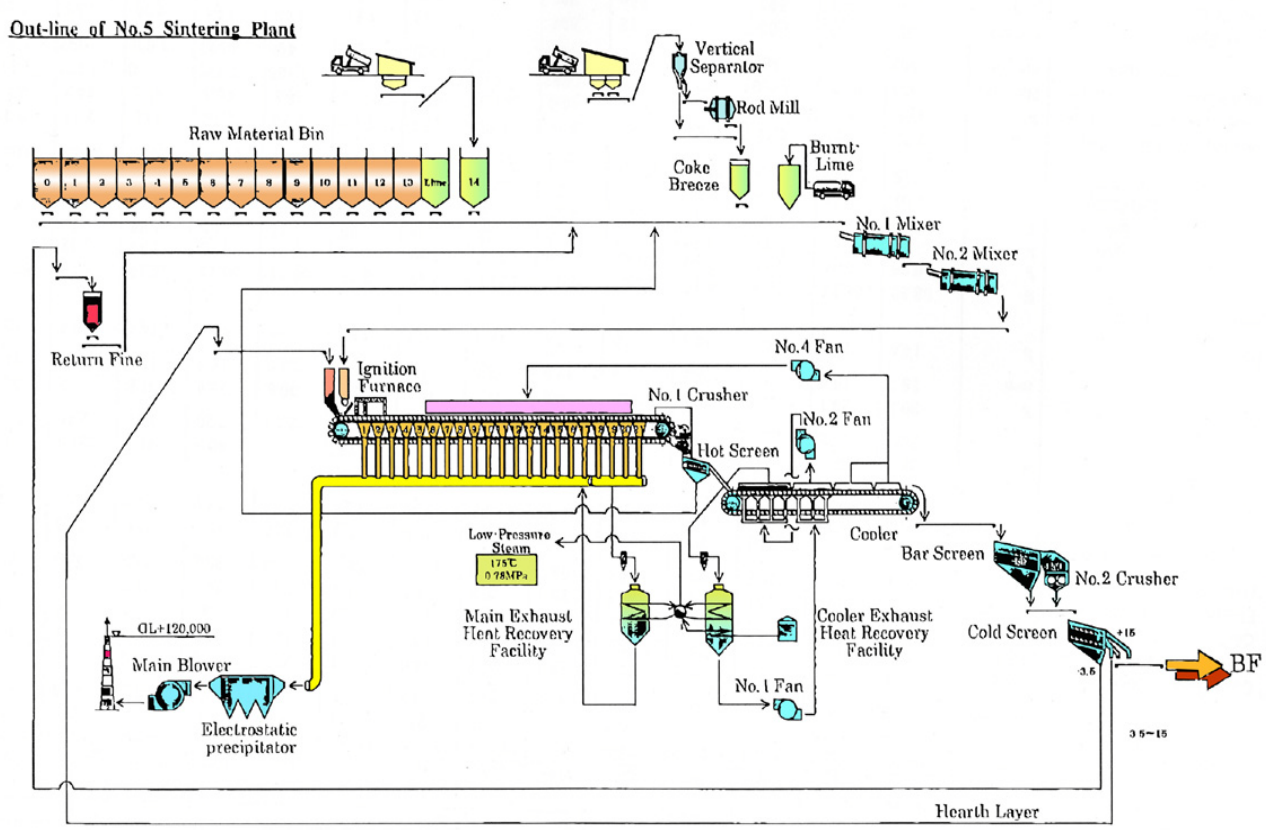


Figure 1.8: Flow diagram of No. 4 Sintering Plant, Wakayama Steel Works, Sumitomo Metal Industries

Commercial Status: Mature

Contact information:
Sumitomo Metal Industries, Ltd.
http://www.sumitomometals.co.jp

JP Steel Plantech Co.
http://www.steelplantech.co.jp

1.1.9 Multi-slit Burner in Ignition Furnace

Description:
Multi-slit burners produce one wide, large stable flame, which eliminates "no flame" areas and supplies minimum heat input for ignition, therefore saving energy.

Energy/Environment/Cost/Other Benefits:
- Total heat input for ignition was reduced by approximately 30% compared with conventional burner in Wakayama Steel Works of Sumitomo Metals in Japan

Block Diagram or Photo:

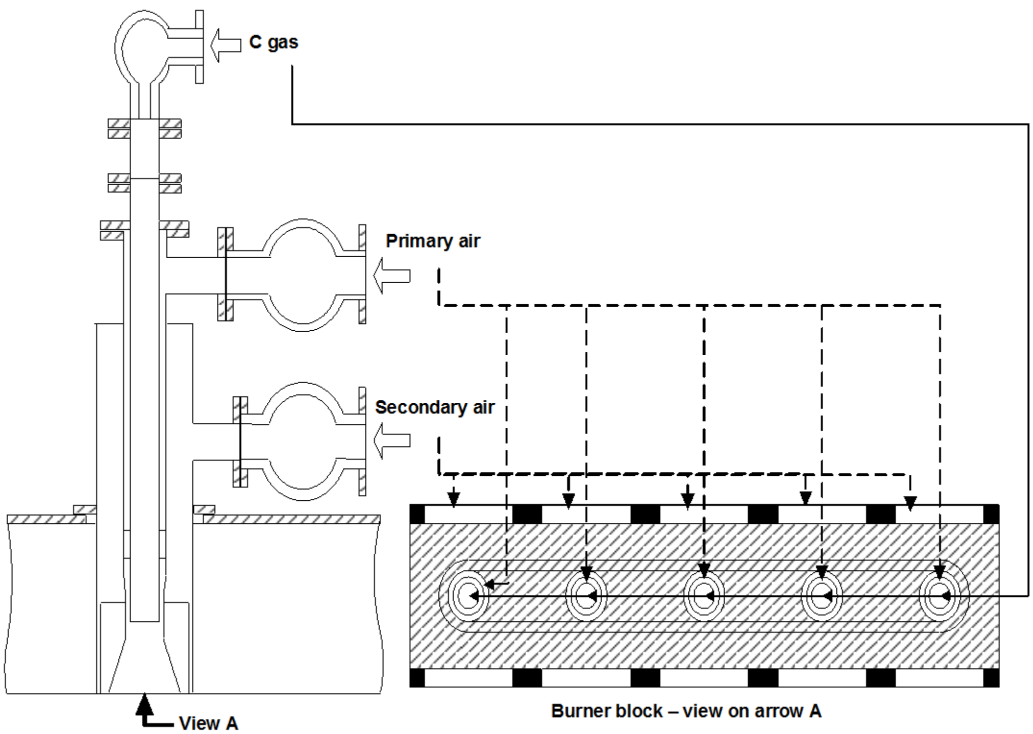


Figure 1.9: Outline of multi-slit burner

Commercial Status: Mature

Contact information:
Sumitomo Metal Industries, Ltd.
http://www.sumitomometals.co.jp

JP Steel Plantech Co.
http://www.steelplantech.co.jp

Installation information:
The burners have been installed in Sumitomo Metals in Japan and many steel works in China and other countries

1.1.10 Equipment to Reinforce Granulation

Description:
A high-speed mixer and a drum mixer (depicted inside the dashed lines in Figure 1.10) are added to the conventional systems for producing granulated ore.

Energy/Environment/Cost/Other Benefits:

- Reinforced granulation at Wakayama Steel works found:
  - Productivity increased from 34.7 to 38.3 t/day m^2
  - Water content increased from 7.0 to 7.3%
  - Granulation rate increased by 45%
  - Permeability increased by 10%
  - Flame front speed increased by 10%
  - Return fine rate decreased less than 1%

Block Diagram or Photo:

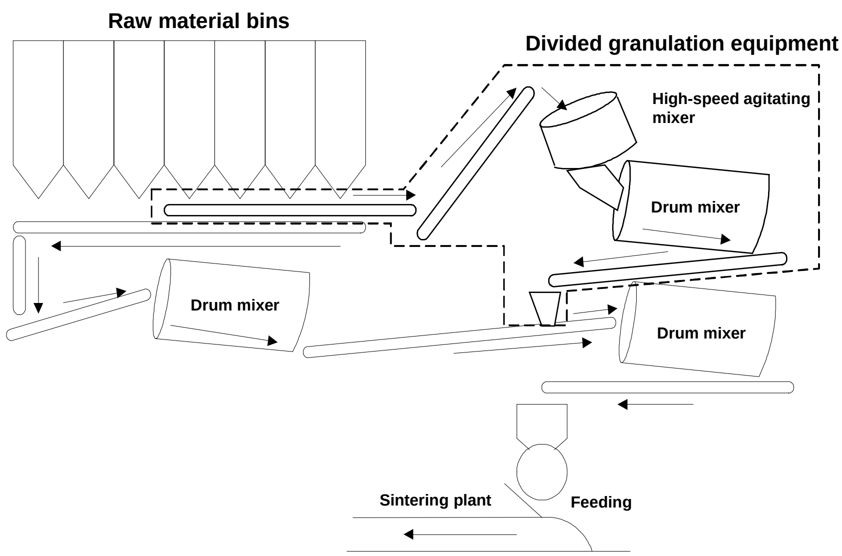


Figure 1.10: Outline of equipment to reinforce granulation (No. 4 Sintering Plant, Wakayama Steel Works, Sumitomo Metal Industries)

Commercial Status: Mature

Contact information:
Sumitomo Metal Industries, Ltd.
http://www.sumitomometals.co.jp

1.1.11 Biomass for Iron and Steel Making

Description:
Biomass utilization practices for iron and steelmaking are being developed to replace coke breeze in the sintering process. Charcoal has been found to be as effective a fuel and reductant as high rank coals for the bath smelting of iron ores and wood char has been shown to be a suitable replacement for coke breeze in the sintering process, resulting in process improvements and reduction of acid gas levels in process emissions.

Energy/Environment/Cost/Other Benefits:

- Substantial reductions in CO_2 emissions
- Reductions in acid gas emissions
- Improved carburization rates and increased product quality
- Reduced demand for fluxing agents
- Lower slag volume and levels of process wastes
- Higher productivity through use of more reactive carbon

Block Diagram or Photo:

Figure 1.11: Injection of charcoal into a molten iron bath at CSIRO Minerals

Commercial Status: Emerging

Contact information:
Sharif Jahanshahi
http://www.minerals.csiro.au

1.1.12 Exhaust Gas Treatment Through Additive Injection and Bagfilter Dedusting

Description:
Sintering off-gas, laden with particulate matter, acid gases (SO_2, HCl, HF), heavy metals (Hg, Pb) and hazardous organic pollutants (Dioxins/Furans, VOCs) are first treated in a vertical conditioning reactor by injection of absorbents and adsorbents, along with air atomized water to remove acid gases, heavy metals and organics. The treated gas is further cleaned in a bagfilter to remove particulate matter. A portion of the dust catch from the filter is recirculated to the reactor to minimize the requirements for fresh absorbents and adsorbents.
Energy/Environment/Cost/Other Benefits:

- Dust emissions of less than 5 mg/Nm^3
- Dioxin/Furan emissions of less than 0.1 ng TEQ/Nm^3
- Mercury removal of about 97%
- Lead removal of about 99%
- HCl/HF removal of greater than 90%
- Condensables/VOCs removal of about 99%
- SO_2 emissions considerably reduced
- Lower operating costs due to recycling of additives

Block Diagram or Photo:

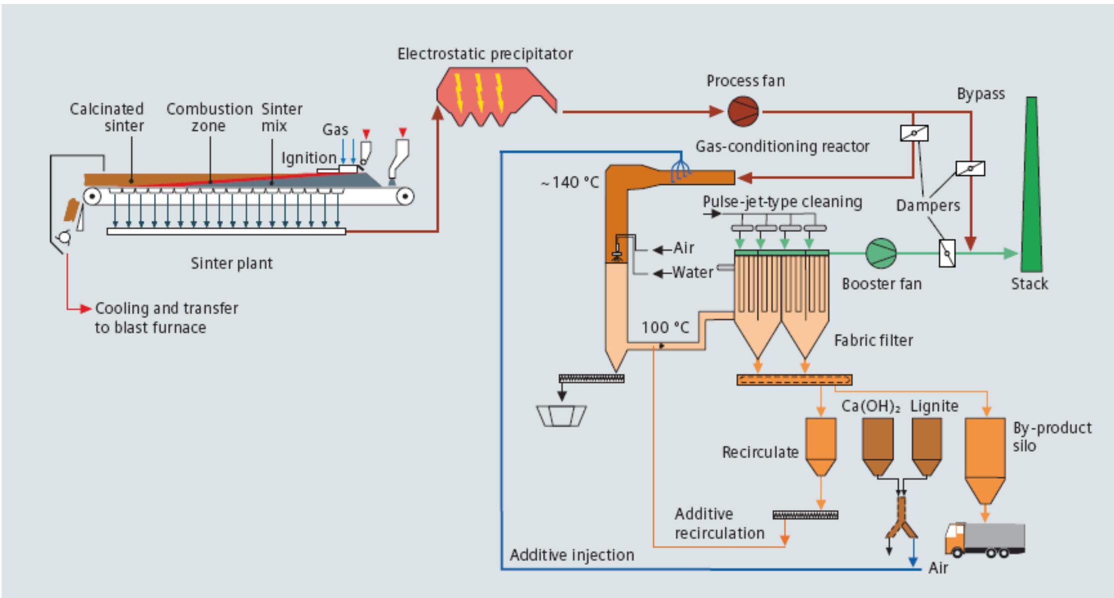


Figure: Process Flow Diagram of Additive Injection and Bag filter Dedusting

Commercial Status: Mature

Contact Information:
Siemens VAI – Metals Technologies GmbH & Co. www.siemens-vai.com
Installation: Full scale facility is installed at voestalpine Stahl GmbH, Linz, Austria

References:

Siemens VAI "Maximized Emission Reduction of Sintering- SIMetal^{CIS} MEROS Plant"

2 Cokemaking

2.1 Super Coke Oven for Productivity and Environmental Enhancement towards the 21st Century (SCOPE21)

Description:
Super Coke Oven For Productivity and Environmental Enhancement towards the 21st Century (SCOPE21), established through a ten year national program in Japan, replaces existing coke ovens with a new process that expands upon the previous choices for coal sources, while increasing productivity, decreasing environmental pollution, and increasing energy efficiency compared to the conventional cokemaking process.

SCOPE21 has three sub-processes as shown in the block diagram: (1) rapid preheating of the coal charge, (2) rapid carbonization, and (3) further heating of coke carbonized up to medium temperatures. The aim of dividing the whole process into three is to make full use of the function of each process in order to maximize the total process efficiency.

Energy/Environment/Cost/Other Benefits:
- Improved coke strength; Drum Index increased by 2.5 (DI^{150}) over conventional coking
- Reduced coking time from 17.5 hours to 7.4 hours
- Increased potential use of poor coking coal from 20 to 50%
- Productivity increased 2.4 times
- NOx content reduced by 30%
- No smoke and no dust
- Energy consumption reduced by 21%
- NEDO reports the CO_2 reduction of 400,000 t-CO_2/year[5]
- Reduction in production cost by 18% and construction cost by 16%

Block Diagram or Photo:

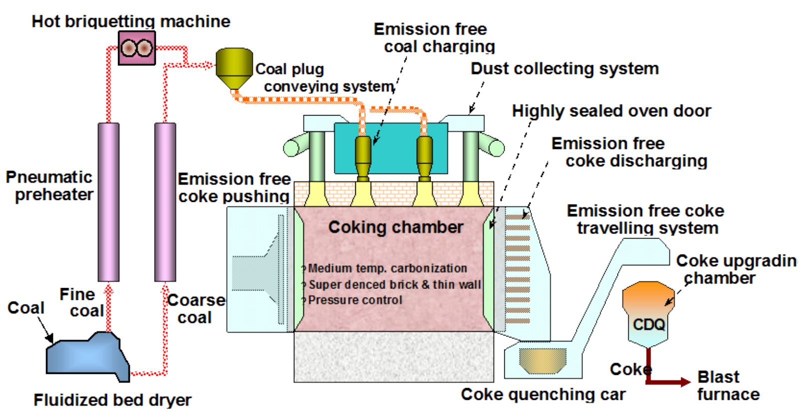


Figure 2.1: Schematic diagram of SCOPE21 process flow

[5] NEDO (New Energy and Industrial Technology Development Organization, Japan), 2008. *Global Warming Countermeasures: Japanese Technologies for Energy Savings/GHG Emissions Reduction (2008 Revised Edition).* Available at: http://www.nedo.go.jp/library/globalwarming/ondan-e.pdf

Commercial Status: Mature

Contact Information:
Japan Iron and Steel Federation
http://www.jisf.or.jp/en/index.html

2.2 Coke Dry Quenching

Description:

Coke dry quenching is an alternative to the traditional wet quenching of the coke. It reduces dust emissions, improves the working climate, and recovers the sensible heat of the coke. Hot coke from the coke oven is cooled in specially designed refractory lined steel cooling chambers by counter-currently circulating an inert gas media in a closed circuit consisting of a cooling chamber, s dust collecting bunker, a waste heat boiler, dust cyclones, a mill fan, a blowing device (to introduce the cold air form the bottom) and circulating ducts. Dry coke quenching is typically implemented as an environmental control technology. Various systems are used in Brazil, Finland, Germany, Japan and Taiwan[6], but all essentially recover the heat in a vessel where the coke is quenched with an inert gas (nitrogen). The heat is used to produce steam, which may be used on-site or to generate electricity.

Energy/Environment/Cost/Other Benefits:

- Energy recovered is approximately 400-500 kg steam/t, equivalent to 800-1200 MJ/t coke[7, 8]. Others estimate energy conservation through steam generation (0.48T/T coke).[9] Electricity generation.
- New plant costs are estimated to be $50/t coke, based on the construction costs of a recently built plant in Germany[10]; retrofit capital costs depend strongly on the lay-out of the coke plant and can be very high, up to $70 to $90/GJ saved[11]. NEDO from Japan gives 3.6 years for the payback period of CDQ (including the construction costs)[12]
- Decreased dust, CO_2 and SOx emissions. NEDO gives an estimate for GHGs emission reduction of up to 137,000 ton CO_2/year
- Increased water efficiency
- Better quality coke produced, improved strength of coke by 4%

Block Diagram or Photo:

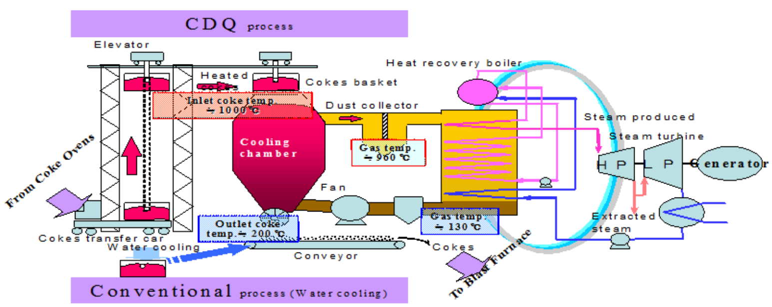


Figure 2.2: Coke quenching process

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[6] International Iron and Steel Institute, 1993. World Cokemaking Capacity, Brussels, Belgium: IISI.
[7] Stelco, 1993. Present and Future Use of Energy in the Canadian Steel Industry, Ottawa, Canada: CANMET.
[8] Dungs, H. and U. Tschirner, 1994. "Energy and Material Conversion in Coke Dry Quenching Plants as Found in Existing Facilities," Cokemaking International 6(1): 19-29.
[9] Indian delegation additional information provided April 2007.
[10] Nashan, G., 1992. "Conventional Maintenance and the Renewal of Cokemaking Technology," In: IISI, Committee on Technology, The Life of Coke Ovens and New Coking Processes under Development, Brussels: IISI.
[11] Worrell, E., J.G. de Beer, and K. Blok, 1993. "Energy Conservation in the Iron and Steel Industry," in: P.A. Pilavachi (ed.), Energy Efficiency in Process Technology, Amsterdam: Elsevier Applied Science.
[12] NEDO (New Energy and Industrial Technology Development Organization, Japan), 2008. *Global Warming Countermeasures: Japanese Technologies for Energy Savings/GHG Emissions Reduction (2008 Revised Edition).* Available at: http://www.nedo.go.jp/library/globalwarming/ondan-e.pdf

Commercial Status: Mature

Contact Information:	Shijiro Uchida, Nippon Steel Engineering http://www/nsc-eng.co.jp	Mecon Ltd., India ranchi@mecon.co.in

Installation information: Visakhapatnam Steel Plant in Andhra Pradesh, India (1989).

2.3 Coal Moisture Control

Description:
Coal moisture control uses the waste heat from the coke oven gas to dry the coal used for coke making. The moisture content of coal varies, but it is generally around 8-9% for good coking coal[13]. Drying further reduces the coal moisture content to a constant 3-5%[14,15], which in turn reduces fuel consumption in the coke oven. The coal can be dried using the heat content of the coke oven gas or other waste heat sources.

Energy/Environment/Cost/Other Benefits:
- Fuel savings of approximately 0.3 GJ/t[8, 9]
- Coal moisture control costs for a plant in Japan were $21.9/t of steel[16]
- Coke quality improvement (about 1.7%)[11]
- Coke production increase (about 10%)[17]
- Shorter cooking times
- Decrease in water pollution (ammonia reduction)

Block Diagram or Photo:

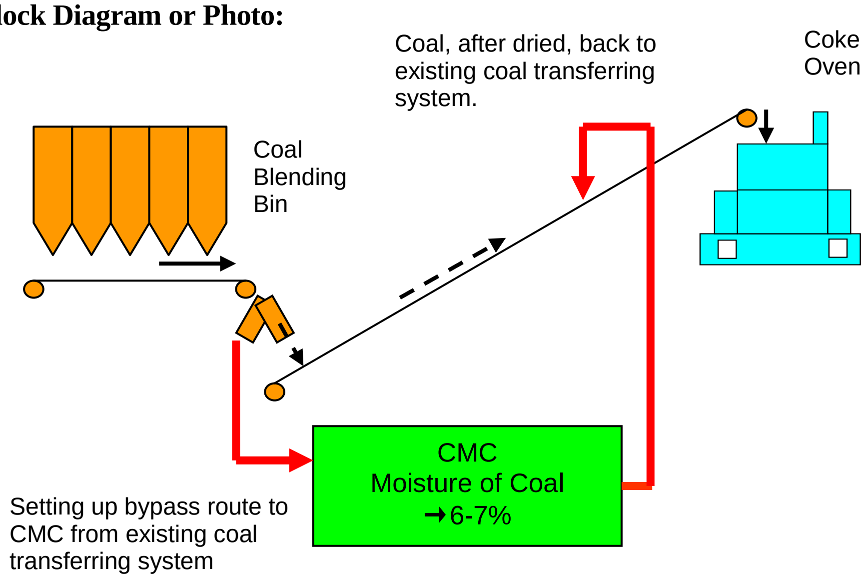

Figure 2.3: Coal moisture control equipment

Commercial Status: Emerging

Contact Information:
Shinjiro Uchida, Nippon Steel Engineering
http://www.nsc-eng.co.jp

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[13] International Iron and Steel Institute, Committee on Technology, 1982. Energy and the Steel Industry, Brussels, Belgium: IISI.
[14] Stelco, 1993. Present and Future Use of Energy in the Canadian Steel Industry, Ottawa, Canada: CANMET.
[15] Uemastsu, H., 1989. "Control of Operation and Equipment Prevents Coke Oven Damage," Ironmaking Conference Proceedings, Warrendale, PA: Iron and Steel Society.
[16] Inoue, K., 1995. "The Steel Industry in Japan: Progress in Continuous Casting," in *Energy Efficiency Utilizing High Technology: As Assessment of Energy Use in Industry and Buildings*, Appendix A: Case Studies, by M.D. Levine, E. Worrell, L. Price, N. Martin. London: World Energy Council.
[17] Fifth International Iron and Steel Congress (1986). p. 312.

2.4 High Pressure Ammonia Liquor Aspiration System

Description:
The High Pressure Ammonia Liquor Aspiration System (HPALA) in effective for controlling charging emissions in coke oven batteries. In this system, the ammoniacal liquor, which is a by-product in the coke oven, is pressurized to about 35-40 bar and injected through special nozzles provided in the gooseneck at the time of charging. This creates sufficient suction inside the oven, thereby retaining pollutants from being released into the atmosphere. The system consists of high-pressure multistage booster pumps, sturdy pipe-work, specially designed spray nozzles, suitable valves and control instruments.

Energy/Environment/Cost/Other Benefits:
- Emissions control
- High reliability and simplicity of operation
- Low operational and maintenance costs
- Appreciable saving in quantity of process steam required and increased raw gas yield/by-products generation, due to elimination of gases vented into the atmosphere

Block Diagram or Photo:

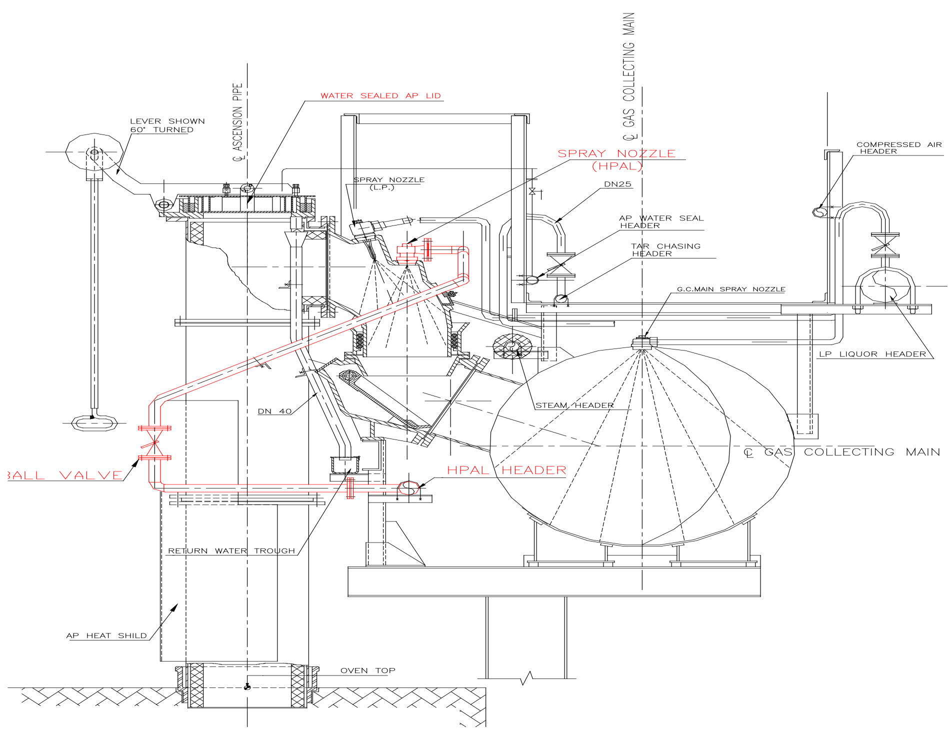

Figure 2.4: Typical installation of HPALA system in Gooseneck for on-main charging

Commercial Status: Mature

Contact Information:	<u>Suppliers</u>:
<u>Consultant</u>:	Nozzle: Lechler India (Pvt.) Ltd., Thane, Maharashtra, India
Mecon Ltd.	Pumps: Sulzer Pumps India Ltd., Thane, Maharashtra, India
ranchi@mecon.co.in	Kirloskar Brothers Ltd., Pune, India

Installation information:
SAIL plants including: Rourkela Steel Plant, Bhilai Steel Plant, and Bokaro Steel Ltd., all in India.

2.5 Modern Leak-proof Door

Description:
Coke oven leaking doors can be a major source of pollution. With the advent of recovery type ovens, the design of oven doors has gone through a process of evolution, beginning from luted doors to the present generation self-regulating zero-leak doors. The important features of the leak-proof door include: (1) a thin stainless steel diaphragm with a knife edge as a sealing frame built in between the door body and the brick retainer, (2) spring loaded regulation on the knife edge for self-sealing, (3) provision for air cooling of the door body, and (4) large size gas canals for easier circulation of gas inside oven.

Energy/Environment/Cost/Other Benefits:
- Minimization of door leakage
- Regulation free operation
- Longer life due to less warping of the air cooled door body
- Reduced maintenance frequency
- Conventional doors can be replaced by leak-proof doors without altering battery/door frame design

Block Diagram or Photo:

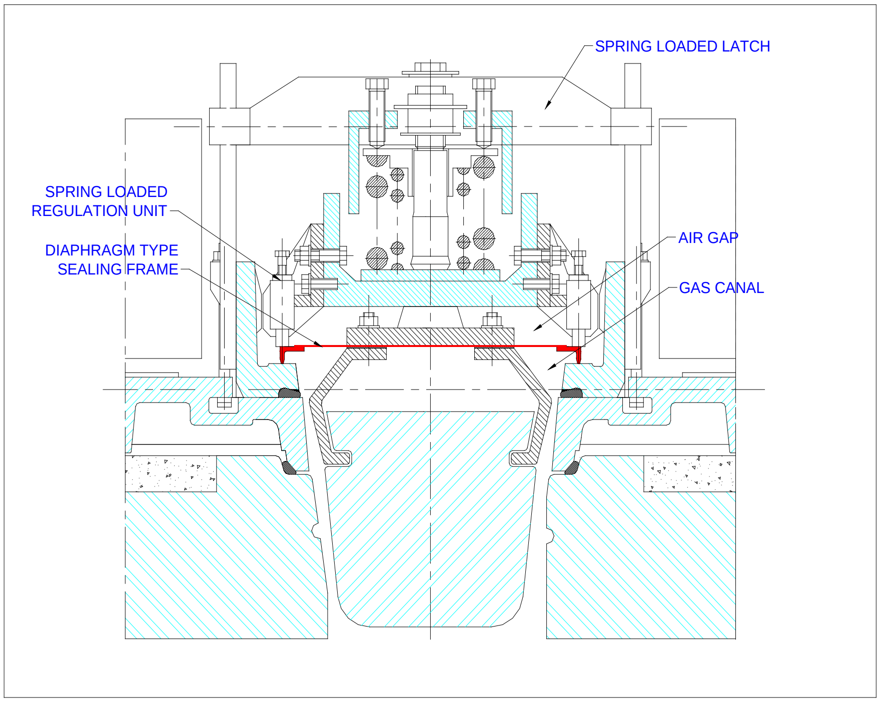

Figure 2.5: Cross-section of modern leak-proof door

Commercial Status: Mature

Contact Information:
Consultant: Mecon Ltd., India
ranchi@mecon.co.in

Suppliers:
Simplex Castings, Ltd., Bhilai, India
BEKEY Engineering Ltd., Bhilai, India

Installation information:
TISCO, Durgapur Steel Plant, Bhilai Steel Plant, and Vishakhapatnam Steel Plant, all in India.

2.6 Land Based Pushing Emission Control System

Description:

The smoke and fumes produced during the pushing of red hot coke contains a huge amount of coke dust (estimated at 11% of the total pollution in the coke oven). Land based pushing emission control systems mitigate this pollution. It consists of three parts: (1) a large gas suction hood fixed on the coke guide car and moving with the coke guide, sending fumes to the coke side dust collecting duct; (2) the dust collection duct; and (3) the final equipment for smoke purification on the ground (ground piping, accumulator cooler, pulse bag dust collector, silencer, ventilation unit, stack, etc). The large amount of paroxysmal high-temperature smoke produced during coke discharging is collected under the hot float fan into the large gas suction hood installed in the coke guide car, and enters the dust collection duct through the other equipment. The air is dissipated into the atmosphere after purification by the pulse dust collector and after being cooled by the accumulator cooler. The total de-dusting system is controlled by PLC.

Energy/Environment/Cost/Other Benefits:

- Elimination of pushing emission up to the large extent

Block Diagram or Photo:

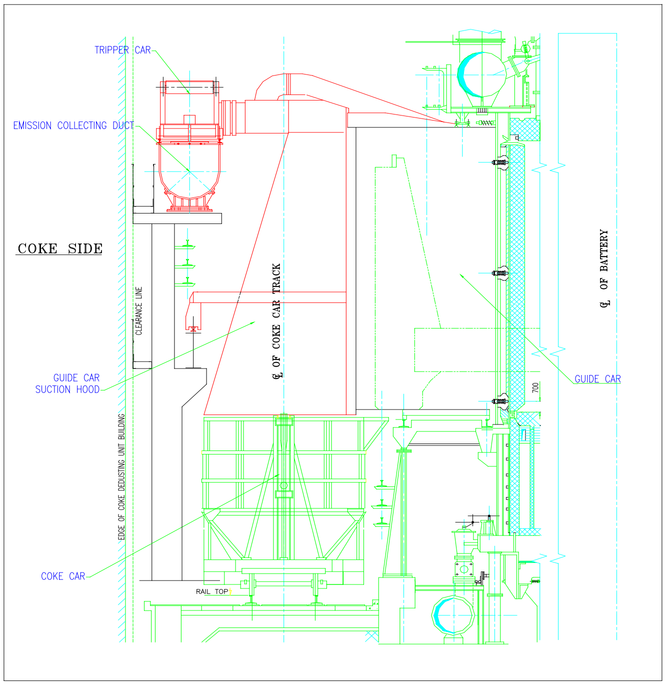

Figure 2.6: Land based pushing emission control system

Commercial Status: Emerging

Contact Information:

<u>Consultant</u>:
Mecon Ltd., Ranchi, India
ranchi@mecon.co.in

<u>Suppliers</u>:
Thermax India
Pune, BEC, India

Installation information:

New projects at COB no. 4 of Vishakhapatnam Steel Plant, India, Bhushan Steel & Strips Ltd. in Angul, Orissa, India, Jindal Stainless in Duburi, Orissa, India, and Jindal South West in Karnataka, India.

2.7 Coke Plant – Automation and Process Control System

Description:
Automation and process control of the coke battery heating and machines is achieved using a Level 2 control system that conducts various process model calculations based upon the process data collected from a Level 1 automation system.
Energy/Environment/Cost/Other Benefits:

- Lower energy consumption through reduction in fuel gas consumption
- Stabilize coke battery operations and conditions
- More consistent coke quality
- Reduced environmental emissions
- Increased battery life time
- Reporting and archiving of process and production data

Block Diagram or Photo:

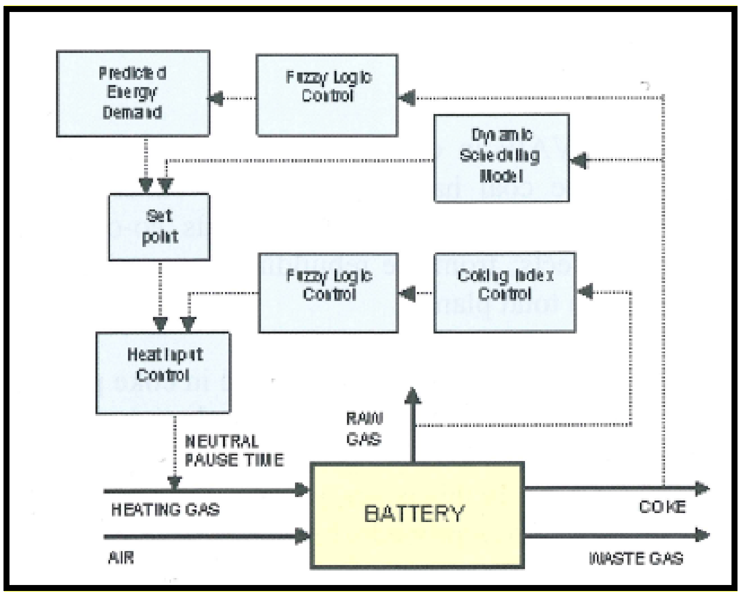

Figure 0-1: Principles of Dynamic Heating Control Model

Commercial Status: Mature

Contact Information:
OEMs – VAI Finland (VAIF) - http://www.industry.siemens.com/metals/en/

References:
The 5th European Coke and Ironmaking Congress Cokemaking Technology from VAI Finland-Good for the Environment, Good for Quality, Mr. Ismo Piirainen, Mr. Olaus Ritamäki

2.8 Heat-recovery (non-recovery) Coke Battery

Description:

Similar to by-product type coke battery selected coals are screened, crushed to less than 3mm and blended based on their petrography to produce a high quality coke whilst using the most cost effective input coals. The blend is charged by conveyor or stamp charging machine through the oven door into the coke oven and coke is formed by the destructive distillation of coal at temperatures of approximately 1000°C and higher. The coke oven consists of a large silica refractory cavity ~ 3.5 m wide and ~14 m long. The coal bed is 1.4-1.6 m thick. Figure shows a cross section through a heat-recovery oven.The coking cycle is about 48 hours. The coke is pushed from the oven into a quench car which transports it to the quenching tower to cool and stabilize the coke. Currently only wet quenching is in use for heat-recovery coke battery. After quenching coke is transported to the blast furnace or stockpile. Unlike the by-product type of coke plant, in heat-recovery cokemaking, all of the volatiles in the coal are burned within the oven to provide the heat required for the cokemaking process. The oven is a horizontal design and operates under negative pressure. Primary combustion air is introduced though ports in the oven doors which partially combusts the volatiles in the oven chamber. Secondary air is introduced to complete the combustion process into the sole flues which run in a serpentine fashion under the coal bed. The design of the flues and the control of the air flow allow the coking rate at the top and bottom of the coal bed to be equalized. Due to the temperatures generated, all of the toxic hydrocarbons and by-products are incinerated within the oven. Hot gases pass in a waste gas tunnel to heat recovery steam generators (HRSGs) where high pressure steam is produced for either heating purposes or power generation. The cool waste gas is cleaned in a flue gas desulphurization plant prior to being discharged to atmosphere.

Energy/Environment/Cost/Other Benefits

- Low capital cost without co-generation plant. Capital cost is comparable or higher than for by-product type battery if co-generation plant is included
- Lower particulate matter emissions and practically zero VOC emissions.
- Comparable SOx emissions and possible higher NOx
- Electrical power production about 630-700 kwh/t coke
- Better coke quality
- Lower coke yield
- Comparable operating cost
- Requires significant footprint

Block Diagram or Photo:

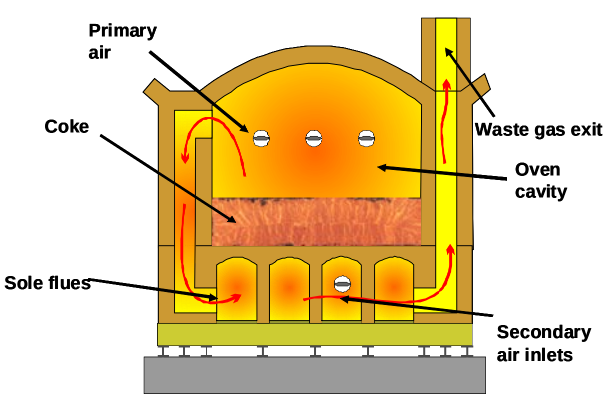

Figure 1: Cross section through a heat-recovery coke oven

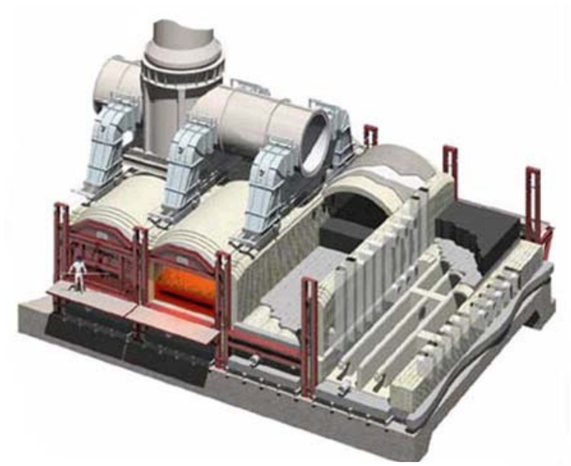

Figure 2: Heat-recovery coke battery. General arrangement

Commercial Status: Mature

Contact information: Sun Coke, USA; Udhe, Germany; ACRE, China

3 Ironmaking

3.1 Blast Furnace Ironmaking

3.1.1 Top Pressure Recovery Turbine

Description:
Top Pressure Recovery Turbine (TRT) is a power generation system, which converts the physical energy of high-pressure blast furnace top gas into electricity by using an expansion turbine. Although the pressure difference is low, the large gas volumes make the recovery economically feasible. The key technology of TRT is to secure the stable and high-efficiency operation of the expansion turbine in dusty blast gas conditions, without harming the blast furnace operation.

Energy/Environment/Cost/Other Benefits:
- Generates electric power of approximately 40-60 kWh/t pig iron
- Japanese Integrated Steel Works:
  - Generates more than 8% of electricity consumed in Japanese ironworks (about 3.33 TWh)
- Excellent operational reliability, abrasion resistant
- Suitable for larger furnaces and higher temperature gases compared to Bag filter systems
- Wet TRT System (US):
  - Typical investments of about $20/t power recovery of 30 kWh/t hot metal[18]
  - No combustion of BF gas
- Dry TRT System, e.g., Venturi Scrubber- Electrostatic Space Clear Super (VS-ESCS):
  - Lower water consumption compared with wet type
  - Raises turbine inlet temperature, increasing power recovery by about 25-30%[19]
  - More expensive than wet type, $28/t hot metal[2]. NEDO from Japan gives 1.8 years for the payback period of VS-ESCS (including the construction costs)[20]

Block Diagram or Photo:

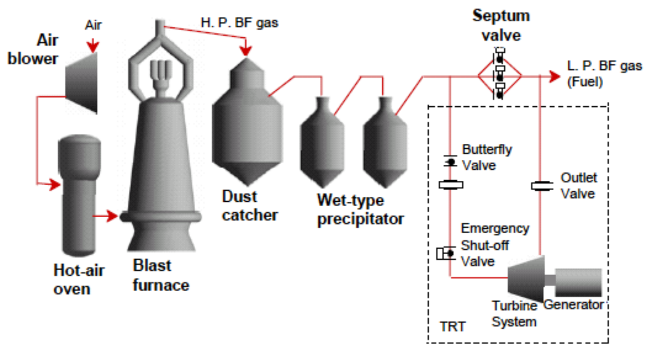

Figure 3.1: Flow diagram of TRT system (wet type)

[18] Inoue, K., 1995. "The Steel Industry in Japan: Progress in Continuous Casting," in *Energy Efficiency Utilizing High Technology: As Assessment of Energy Use in Industry and Buildings*, Appendix A: Case Studies, by M.D. Levine, E. Worrell, L. Price, N. Martin, London: World Energy Council.
[19] Stelco, 1993. *Present and Future Use of Energy in the Canadian Steel Industry*, Ottawa, Canada: CANMET.
[20] NEDO (New Energy and Industrial Technology Development Organization, Japan), 2008. *Global Warming Countermeasures: Japanese Technologies for Energy Savings/GHG Emissions Reduction (2008 Revised Edition)*. Available at: http://www.nedo.go.jp/library/globalwarming/ondan-e.pdf

Commercial Status: Mature

Contact information:

Kawasaki Heavy Industries, Ltd.
http://khi.co.jp/products/gendou/ro/ro_01.html

Shinjiro Uchida, Nippon Steel Engineering
http://www.nsc-eng.co.jp

Mitsui Engineering & Shipbuilding Co., Ltd.
http://mew.co.jp/business/english/energy/energy_10.html

3.1.2 Pulverized Coal Injection (PCI) System

Description:
Pulverized coal injection replaces part of the coke used to fuel the chemical reaction, reducing coke production, thus saving energy. The increased fuel injection requires energy from oxygen injection, coal, and electricity and equipment to grind coal. The coal replaces the coke, but coke is still used as a support material in the blast furnace (BF). The maximum injection depends on the geometry of the BF and impact on the iron quality (e.g., sulfur).

Energy/Environment/Cost/Other Benefits:

- Reduces emissions of coke ovens
- Increased costs of oxygen injection and maintenance of BF and coal grinding equipment offset by lower maintenance costs of existing coke batteries and/or reduced coke purchase costs, yielding a net decrease in operating and maintenance costs, estimated to be $15/t[21], but a cost savings of up to $33/t are possible, resulting in a net reduction of 4.6% of costs of hot metal production[22]
- Decreased frequency of BF relining
- Improved cost competitiveness with cost reduction of hot metal
- Investment of coal grinding equipment estimated at $50-55/t coal injected[23]. NEDO from Japan gives a wide range of 6.2 – 24.3 years for the payback period of PCI (including the construction costs)[24]
- High reliability and easy operation
- Increased productivity
- Uniform transfer of pulverized coal
- No moving parts in injection equipment
- Even distribution to Tuyeres

---

[21] International Energy Agency, 1995. *Energy Prices and Taxes, First Quarter 1995*, Paris: IEA.
[22] Oshnock, T.W., 1995a. "Pulverized Coal Injection for Blast Furnace Operation, Part IV," *Iron & Steelmaking* **22**(2): 41-42.
[23] Farla, J.C.M., E. Worrell, L. Hein, and K. Blok, 1998. *Actual Implementation of Energy Conservation Measures in the Manufacturing Industry 1980-1994*, The Netherlands: Dept. of Science, Technology & Society, Utrecht University
[24] NEDO (New Energy and Industrial Technology Development Organization, Japan), 2008. *Global Warming Countermeasures: Japanese Technologies for Energy Savings/GHG Emissions Reduction (2008 Revised Edition)*. Available at: http://www.nedo.go.jp/library/globalwarming/ondan-e.pdf

Block Diagram or Photo:

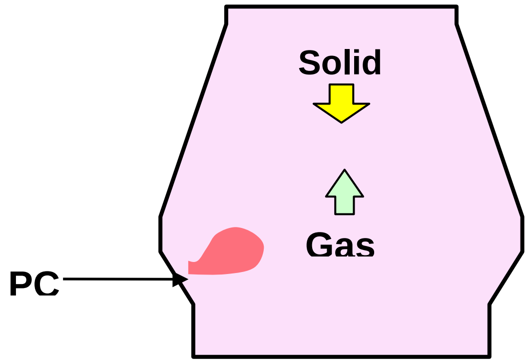

Figure 3.2: Diagram of PCI System

Commercial Status: Mature

Contact information:
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http://www.nsc-eng.co.jp

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www.claudiuspeters.com
paulwurth@paulwurth.com
metals-mining@siemens.com

3.1.3 Blast Furnace Heat Recuperation

Description:
Recuperation systems, e.g., Hot Blast Stove, BFG Preheating System, etc., are used to heat the combustion air of the blast furnace. The exit temperature of the flue gases, approximately 250^0C, can be recovered to preheat the combustion air of the stoves.

Energy/Environment/Cost/Other Benefits:
- Hot Blast Stove:
  - Fuel savings vary between 80-85 MJ/t hot metal[25, 26]
  - Costs are high and depend strongly on the size of the BF, estimated at \$18-20/(GJ saved), equivalent to \$1.4/t hot metal[7]
  - Efficient hot blast stove can run without natural gas
- BFG Preheating System at POSCO in Korea:
  - Anti-corrosion technology with high surface temperatures
  - Economic recovery for low to medium temperature grade heat
  - 426 kJ/kWh reduction in fuel input; thermal efficiency increase of 3.3%
  - Energy savings of 3-5% for boiler, with payback period of within 1.5 years
  - Proven reliability and stability for more than 10 years of operation

[25] Farla, J.C.M., E. Worrell, L. Hein, and K. Blok, 1998. *Actual Implementation of Energy Conservation Measures in the Manufacturing Industry 1980-1994*, The Netherlands: Dept. of Science, Technology & Society, Utrecht University
[26] Stelco, 1993. *Present and Future Use of Energy in the Canadian Steel Industry*, Ottawa, Canada: CANMET.

Block Diagram or Photo:

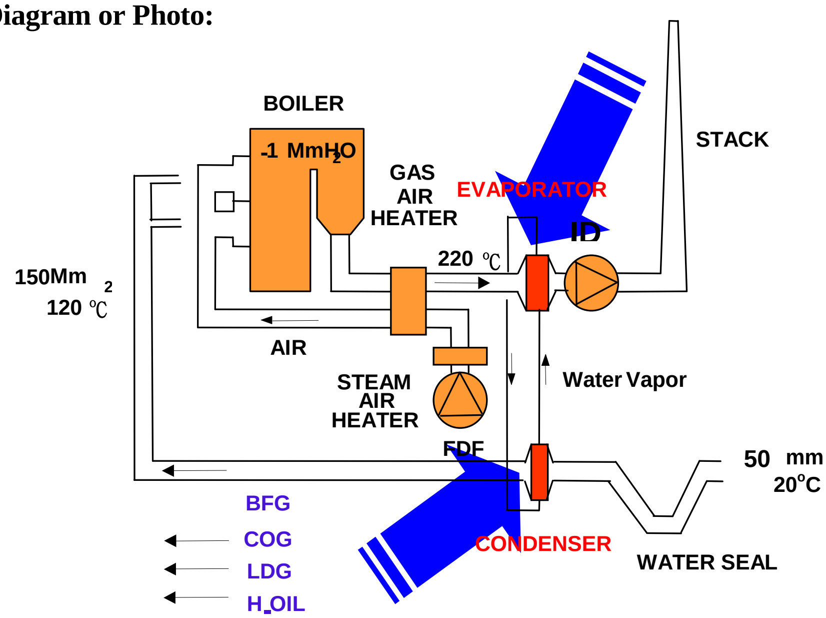

Figure 3.3: BFG Preheating System

Commercial Status: Emerging

Contact information*:*

Yun Sik Jung, Pohang Works, POSCO
+82-54-220-4579
yswilly@posco.co.kr
http://www.posco.co.kr

3.1.4 Improve Blast Furnace Charge Distribution

Description:
Charging systems of old blast furnaces and new blast furnaces are being retrofitted or equipped with the Paul Wurth Bell Less Top (BLT) charging systems. Input materials like coke and sinter are screened before charging. Proper distribution of input materials improves the coking rate and increases production.

Energy/Environment/Cost/Other Benefits:
- Increased fuel efficiency
- Reduced emissions
- Increased productivity
- Improved coking rate

Block Diagram or Photo: None provided

Commercial Status: None provided

Contact information:
Paul Wurth Bell Engineering and Technology
http://www.paulwurth.com/
paulwurth@paulwurth.com

TOTEM Co. Ltd
totem@totem-engineering.com

Siemens AG
http://www.siemens.com/index.jsp
metals-mining@siemens.com

Consultant: bf@ranchi.mecon.co.in

3.1.5 Blast Furnace Gas and Cast House Dedusting

Description:
When blast furnace gas (BFG) leaves the top of the furnace it contains dust particles. Dust particles are removed either with a conventional wet type dedusting system or a dry type dedusting system. Both systems consist of a gravity dust catcher to remove dry large particulate from the BFG stream. The wet fine particulate is then removed in wet type dedusting with a two-stage Venturi or Bisholff scrubber, whilst dry type dedusting does not require water scrubbing and instead employs an electro-precipitator or a bag filter to clean the BFG.

Energy/Environment/Cost/Other Benefits:

- Dust catcher removes about 60% of particulate from BFG[27] which could be bout 3.0 - 3.5 kg/tonne pig iron[28]
- Wet Type Dedusting:
  - Produces gas containing less than 0.05 grams/m^3 of particulate[29]
  - Pressure and noise control devices not necessary
- Dry Type Dedusting:
  - 30% increase in power generated with dry-type TRT system compared to wet type dedusting
  - 7-9 Nm^3/tHM reduction in recirculated water consumption, of which 0.2m^3 is fresh water
  - Eliminates generation of polluted water and slurry
  - Improved gas cleanness with dust content of <5mg/Nm^3
  - 50% less occupied land area than wet type dedusting
  - Minimized investment cost and accelerates project construction, as only accounts for 70% in investment compared to wet type dedusting

Block Diagram or Photo:

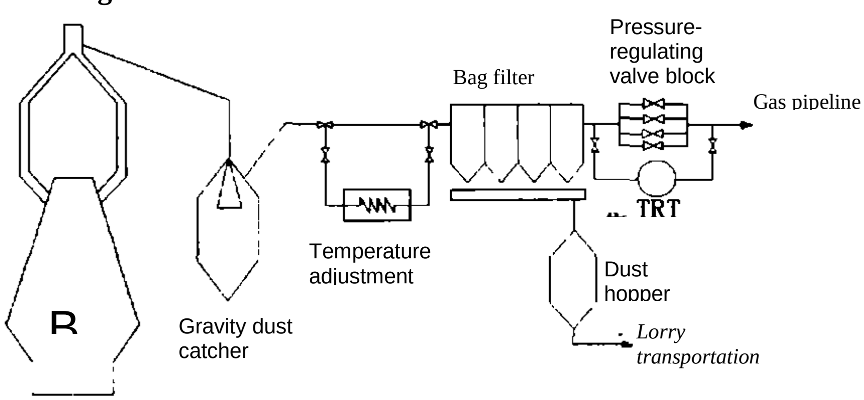

Figure 3.4: BFG Dry Type Dedusting System

Commercial Status: Emerging

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[27] US Department of Energy, Office of Industrial Technologies, 2000. *Energy and Environmental Profile of the US Iron and Steel Industry,* Washington, DC: US DOE, OIT.
[28] NEDO (New Energy and Industrial Technology Development Organization, Japan), 2008. *Global Warming Countermeasures: Japanese Technologies for Energy Savings/GHG Emissions Reduction (2008 Revised Edition).* Available at: http://www.nedo.go.jp/library/globalwarming/ondan-e.pdf

[29] US Environmental Protection Agency. 1995b. *Compilation of Air Pollutant Emission Factors, Vol. I: Stationary Point and Area Sources, IAP-42,* 5th ed.

Contact information:
Laiwu Iron & Steel Corp (Group)
Kakogawa Works, Kobe Steel

3.1.6 Cast House Dust Suppression

Description:
The primary source of blast furnace particulate emissions occurs during casting. Molten iron and slag emit smoke and heat while traveling from the taphole to ladle, or the slag granulator to pit. The cast house dust suppression system is designed to contain emissions. "Dirty" air is drawn through the baghouse, which contains separate collection chambers each with a suction fan, and is then exhausted into the atmosphere. The system has multiple collection hoods: overhead hoods above each taphole and skimmer, and below-floor hoods above each tilting spout.

Energy/Environment/Cost/Other Benefits:
- Individual baghouse collection chambers can be shut down without affecting operation

Block Diagram or Photo:

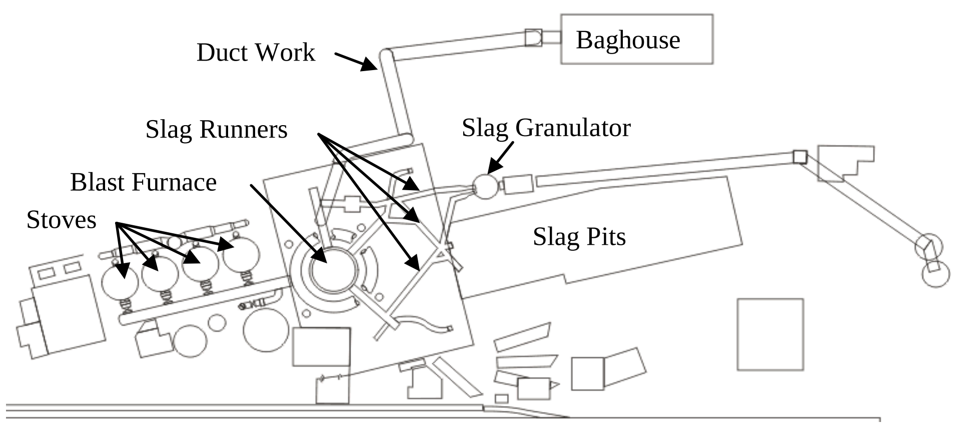


Figure 3.5: Cast house dust suppression system

Commercial Status: Mature

Contact information:
None provided

3.1.7 Slag Odor Control

Description:
Slag odor can be reduced significantly by water granulation. Circulating water is used for blowing (with cooling tower installed).

Energy/Environment/Cost/Other Benefits:

- In water granulation, average slag odor generated is 14 g-S/min, compared to 228 g-S/min found immediately after slag discharge at 800^0C.

Block Diagram or Photo:

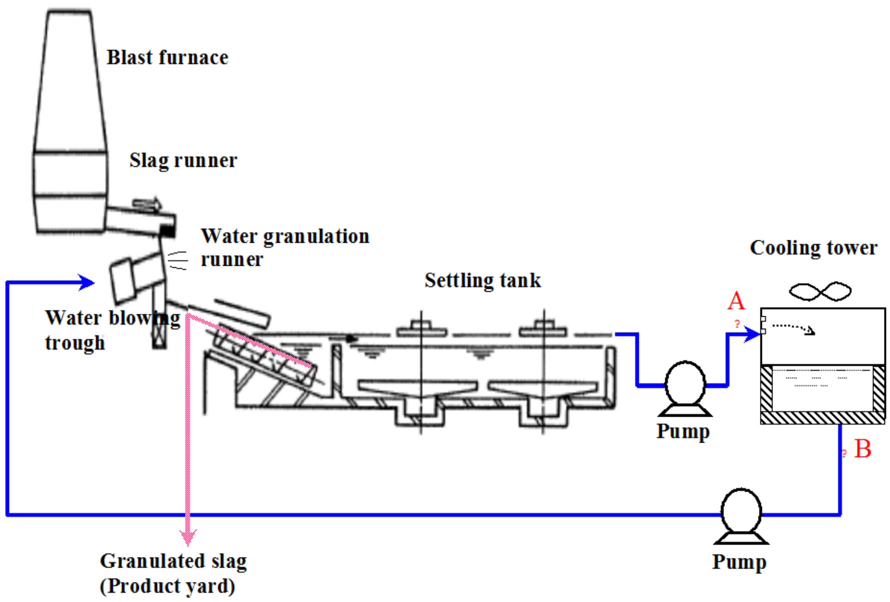


Figure 3.6: Water granulation devise flow (No.1 Blast Furnace at Kakogawa Works, Kobe Steel)

Commercial Status: Mature

Contact information:
Kakogawa Works, Kobe Steel

3.1.8 Blast Furnace – Increase Hot Blast Temperature (>1100 Deg C)

Description:
The hot stoves are fired with (often enriched) BFgas. Several techniques are available to optimise the energy efficiency of the hot stove:
Computer-aided hot stove operation; avoids unnecessary reserves by adapting the energy supply to the actual demand and minimises the amount of enriching gas added (in cases where enrichment takes place).
Preheating of the fuel in conjunction with insulation of the cold blast line and waste gas flue. Sensible heat from the flue gas can be used to preheat the fuel media. The feasibility of this depends on the efficiency of the stoves as this determines the waste gas temperature; e.g. at waste gas temperatures below 250°C heat recovery may not be a technically or economically attractive option. The heat exchanger preferably consists of a heating coil circuit, for economic reasons. In some cases, imported heat may be used, e.g. sinter cooler heat, if the distances are reasonable. A preheated fuel medium reduces energy consumption. At plants which use enriched blast furnace gas, preheating the fuel could mean that enrichment would not longer be necessary.
Improvement of combustion through more suitable burners;
Rapid O2 measurement and subsequent adaptation of combustion conditions.
Energy/Environment/Cost/Other Benefits:

- The total energy savings possible by a combination of techniques is of the order of 0.5 GJ/t pig iron produced. This includes reduced coke and tuyere level injection
- Computer-aided hot stove operation leads to an efficiency improvement of the hot stove of more than 5%. This equals an energy saving of approximately 0.1 GJ/t pig iron. Implementation of computer-aided control could require the construction of a fourth stove in case of three stoves blast furnaces (if possible at all) in order to maximize the benefits.
- Preheating of the fuel media can lead to an energy saving of approximately 0.3 GJ/t pig iron as well.
- Another 0.04 GJ/t pig iron may be saved by improved combustion and adaptation of combustion conditions.

These measures might be attractive from an economic point of view, because energy consumption is reduced and thus money is saved. The profitability depends on the amount of energy saved and on the investment and operational costs of the measures.

Block Diagram or Photo:

Figure: Baosteel Shangha, Meishan, China, Internal Combustion Stoves

Commercial Status: Mature

Contact Information:
VAiron - http://www.industry.siemens.com/metals/en/
Paul Wurth - http://project.paulwurth.com/fs_products_primus.html

References:

European Commission Integrated Pollution Prevention Control (IPPC). Best Available Techniques Reference Document on the Production of Iron and Steel, December 2001
The 5th European Coke and Ironmaking Congress Development of Blast Furnace Operations at SSAB Oyelösund AB Influenced by the Changes in the Coke Market.

3.1.9 Blast Furnace – Increase Blast Furnace Top Pressure (>0.5 Bar Gauge)

Description:
Blast furnace off gas cleaning is performed using either a dust catcher or cyclone in conjunction with an annular gap wet scrubber. The scrubber consists of a movable cone assembly which allows the top pressure of the furnace to be controlled accurately and consistently. Increased top pressure aids good furnace operation and reduced fuel rate by decreasing velocity of the gases and increasing retention time for the gas-solid reactions.

Energy/Environment/Cost/Other Benefits:

- Reduced fuel rate – coke rate and tuyere level injectants
- Reduced hot metal silicon variability
- Increased productivity

Block Diagram or Photo:

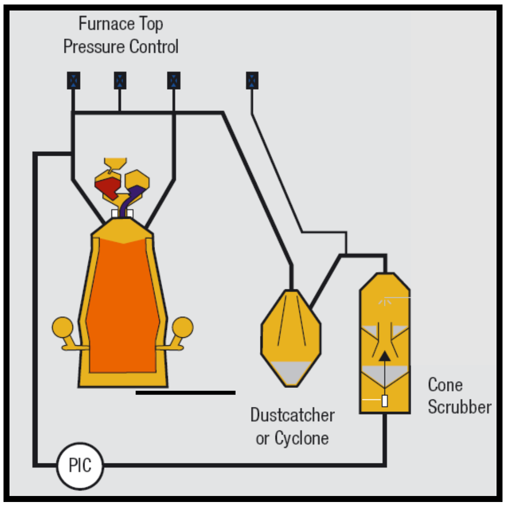


Figure: Blast Furnace Top Pressure Control System

Commercial Status: Mature
Contact Information
Paul Wurth - http://project.paulwurth.com/fs_products_primus.html
SVAI - VAiron - http://www.industry.siemens.com/metals/en/

References: Siemens VAI 2006 Blast Furnace Technology

3.1.10 Optimized Blast Furnace Process Control with Expert System

Description:
Optimized process control of the blast furnace is achieved through an expert system that uses various process models (including burden control, burden distribution, mass and energy balances, silicon prediction and kinetic process models) that observe the blast furnace on a continuous basis and uses the various process models to perform calculations, diagnose (phenomena recognition) process disturbances such as risk of hanging, channeling, slipping and to make changes/corrective actions to the operation such as modification of the rate of reducing agents or changes to the burden distribution. Expert systems can be run in advisory mode or in full closed loop depending on technology supplier and functionality selection.

Energy/Environment/Cost/Other Benefits:
- Lower fuel rate
- Higher productivity
- Reduced variability of hot metal silicon
- Fewer disturbances (slips/hanging) with more even burden descent

Block Diagram or Photo:

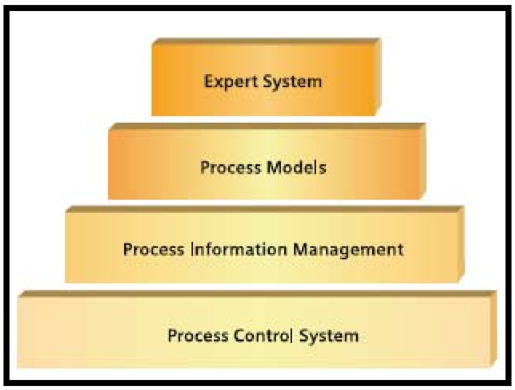


Figure: Solution Packages for Optimized Blast Furnace Performance

Commercial Status: Mature

Contact Information:
VAiron - http://www.industry.siemens.com/metals/en/
Paul Wurth - http://project.paulwurth.com/fs_products_primus.html

References:
Siemens VAI 2006 Blast Furnace Technology
The 5th European Coke and Ironmaking Congress, Expert System Controlled Blast Furnace Operation – the Next Step, Mr. Dieter Bettinger et.al, Mr. Olaus Ritamäki et. al.

3.2 Alternative Ironmaking: Direct Reduction (DRI/HBI) and Direct Smelting

3.2.1 Smelting Reduction Processes

Description:
Smelting reduction processes, including Aumelt Ausiron®, HIsmelt®, CCF, DIOS and COREX, involve the pre-reduction of iron ore by gases coming from a hot bath. The pre-reduced iron is then melted in the bath, and the excess gas produced is used for power generation, production of direct reduced iron (an alternative iron input for scrap), or as fuel gas. In this way, smelting reduction eliminates the need for coke and sintering, and future processes will also eliminate ore preparation.

Energy/Environment/Cost/Other Benefits:

- Low capital and operating costs:
  - 5-35% below production cost of conventional route[30]
  - Direct use of iron ore fines/steel plant dusts and thermal coals
  - No coke ovens, sinter plants, blending yards
  - Single furnace with direct waste energy recovery
- Low environmental impact:
  - No coke-oven or sinter plant emissions, and reduced CO_2, SO_2 and NOx, no production of dioxins, furans, tars or phenols
  - Recycling of steel plant dusts and slag, making effective uses of coal energy
- High quality iron product, with impurities reported to the slag not the metal
- Greater flexibility in the range of raw materials accepted, including steel plant wastes and high phosphorous ores

Block Diagram or Photo:

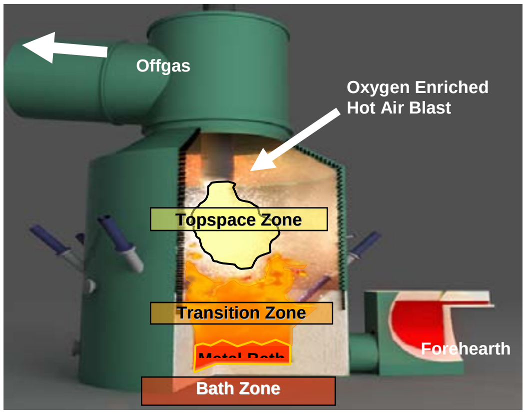


Figure 3.7: Outline of Smelting Reduction Process

Commercial Status: Emerging

Contact information:

HIsmelt Corporation
http://www.hismelt.com.au

Ausmelt Limited Pty. Ltd.
http://www.ausmelt.com.au

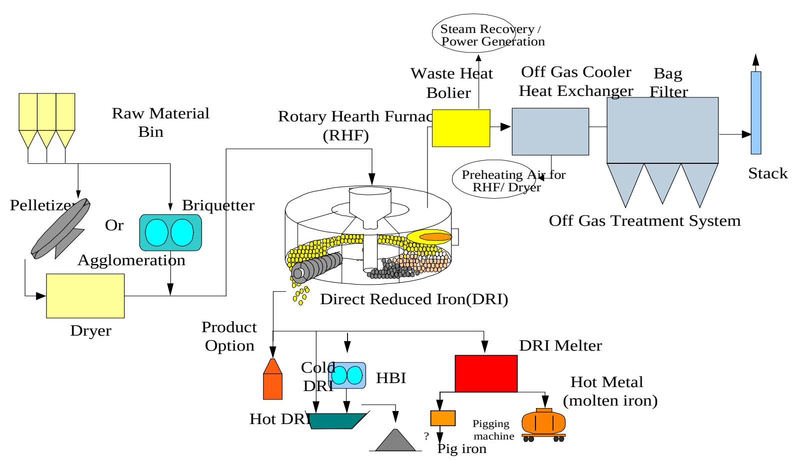
[30] De Beer, J., K. Block, E. Worrell. 1998a. "Future Technologies for Energy-Efficient Iron and Steelmaking." In *Annual Review of Energy and the Environment.* Vol. 23: 123-205; 1998b. "Long-term energy-efficiency improvements in the paper and board industry." In *Energy.* 23 (1): 21-42.

3.2.2 Direct Reduction Processes

Description:
Direct reduced iron (DRI) is produced through the reduction of iron ore pellets below the melting point of the iron. This is achieved with either natural gas (MIDREX® process) or coal-based (FASTMET® process) reducing agents. The DRI produced is mainly used as a high quality iron input in electric arc furnace (EAF) plants.

Energy/Environment/Cost/Other Benefits:
- Pre-treatment of raw material is not necessary
- Eliminates coke oven
- Low capital and operating costs
- FASTMET® Process:
  - Faster speed and lower temperatures for reduction reaction
  - Fuel useage can be reduced; not necessary to recover and reuse exhaust gases as secondary combustion of close to 100% is achieved in the rotary hearth furnace
  - Low heat loss, as reduced iron is fed to the melting furnace for hot metal production without cooling
  - Low emissions – 0.3-1.5 kg/THM NOx, 2.4 kg/THM SOx, and 0.3 kg/THM PM_{10} (-particulate matter less than 10.0 microns in diameter)
  - Energy consumption is 12.3 GJ/t-hot metal less than mini blast furnace; CO_2 is reduced by 1241 kg/t hot metal

Block Diagram or Photo:



Note :
* Agglomeration method will be decided depending on raw material conditions.
* Waste heat bolier is optional.

Figure 3.8: FASTMET® Process Flow

Commercial Status: None provided

Contact information:
Japan Iron and Steel Federation
http://www.jisf.or.jp/en/index.html

3.2.3 ITmk3 Ironmaking Process

Description:
ITmk3® uses the same type of rotary hearth furnace (RHF) as the FASTMET® process[31]. The process uses low-grade iron ore and coal (but other feedstocks can be used as a supplement) to produce iron nuggets of superior quality to direct reduced iron (97% iron content), but similar to pig iron. The mixing, agglomeration, and feeding steps are the same, but the RHF is operated differently. In the last zone of the RHF, the temperature is raised, thereby melting the iron ore and enabling it to easily separate from the gangue. The result is an iron nugget containing iron and carbon, with almost no oxygen or slag.

Energy/Environment/Cost/Other Benefits:
- Low capital and operation costs
- Excellent operational reliability
- 30% energy savings over integrated steel making; 10% savings over EAF
- Process does not require coke oven or agglomeration plant
- All chemical energy of coal is utilized and no gas is exported from the system
- Can reduce emissions by >40%; less NOx, SOx and particulate matter emitted
- Reduction, melting and slag removal occur in just 10 minutes
- Higher scrap recycling in EAF
- Reduces FeO to <2%, minimizing attack to refractories
- Allows production of high quality flat product steel in subsequent basic oxygen furnace due to dilution of tramp elements such as Cu, Pb, Sn and Cr

Block Diagram or Photo:

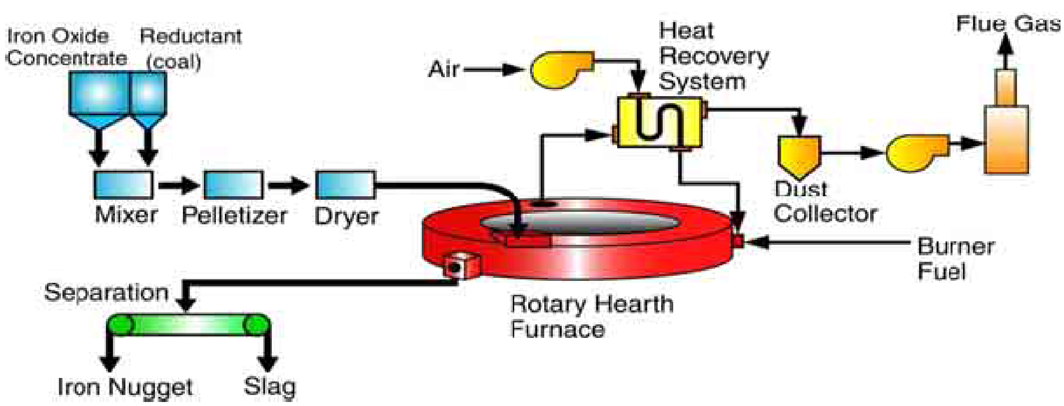


Figure 3.9: Flow sheet for the ITmk3® process illustrates the one-step furnace operation

Commercial Status: Emerging

Contact information:
Mesabi Nugget, LLC
http://mesabinugget.com

[31] Information available at: http://www.midrex.com/handler.cfm?cat_id=80

3.2.4 Paired Straight Hearth Furnace

Description:
The Paired Straight Hearth (PSH) furnace is a new coal-based reduction process for making metallized pellets for Electric Arc Furnace or Smelting processes. It operates at higher production rates and lower energy utilization than conventional rotary hearth processes. The key tall bed design, which protects the bed from reoxidization allows more complete combustion and increases productivity. Carbon is the reductant and the CO evolved in combustion is used as fuel.

Energy/Environment/Cost/Other Benefits:
- High productivity with lower energy consumpting than rotary processes
- Enables higher productivity smelting operations, when used as a pre-reducer with a smelter, to the point that the combined process is a suitable BF/coke oven replacement, using 30% less energy at lower capital cost compared to blast furnace iron making.
- In comparison with Blast Furnace route, the total CO_2 emissions per ton of hot metal produced is expected to decrease by one third.
- Coal is used without requiring gasification
- For EAF operations, the availability of hot metal on-site will bring advantages in power consumption, tap-to-tap time, and thereby energy intensity. The cost reduction is also expected since there is no cokemaking process needed and high volatile coals can be used.

Block Diagram or Photo:

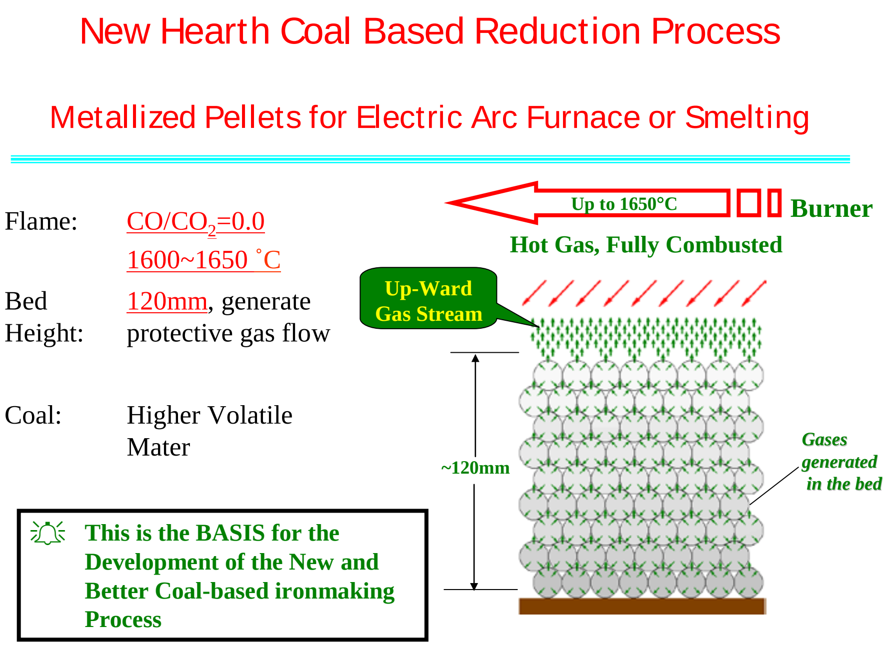


Figure 3.10: PSH process flow

Commercial Status: Emerging

Contact information:
American Iron and Steel Institute
http://www.steel.org

3.2.5 Corex Process

Description:

The Corex process is a two stage direct smelting process, consisting of: 1) melter-gasifier (MG), which melts the DRI and gassifies the coal and 2) DRI shaft furnace mounted above melter-gasifier, which reduces lump ore or pellets to DRI by reducing gas from melter-gasifier.

The shaft furnace is a modified Midrex DRI counter-current reactor without cooling zone where lump ore or/and pellets are reduced to metallization degree of about 85%. The hot DRI at temperature about 800^0C are discharged from the shaft furnace by means of discharge horizontal screw conveyors to the charging pipes of melter-gasifier. The reducing gas enters the bottom of metallization zone. The fresh reducing gas from the MG enters the shaft furnace at approximately 800 °C and then exists from the furnace top at ~450 °C. The MG completes reduction and melting of the DRI. It consists of a fluidized bed resting on a liquid slag and hot metal bath. Coarse coal is charged to the top of MG and charred in the fluidized bed. Oxygen is injected via tuyeres around the circumference of the MG. It forms a raceway, where the oxygen reacts with charred coal to form carbon monoxide. For optimum energy efficiency the process requires the following auxiliaries: 1) CO2 stripping of the shaft top gas enables better utilization of the process gas. After CO2 stripping the rich reducing gas could be recirculated to shaft furnace. 2) In most cases co-generation of the export gas is required due to its high calorific value. 3) Additional DRI shaft furnace could be also installed to utilize the off-gas and to produce equivalent amount of DRI to hot metal from melter-gasifier

Energy/Environment/Cost/Other Benefits

- No need for coking coal and coke
- Environmental benefits compare to blast furnace route
  - CO2 emissions per ton of combined product (hot metal + DRI) are lower by ~20% compared to blast furnace route
  - NOx emissions per ton of combined product are lower by ~30% compared to BF route
  - No VOC emissions and significantly lower SOx emissions
- Fuel rate could be significantly reduced by circulation of the shaft furnace top gas back to the shaft furnace

Block Diagram or Photo:

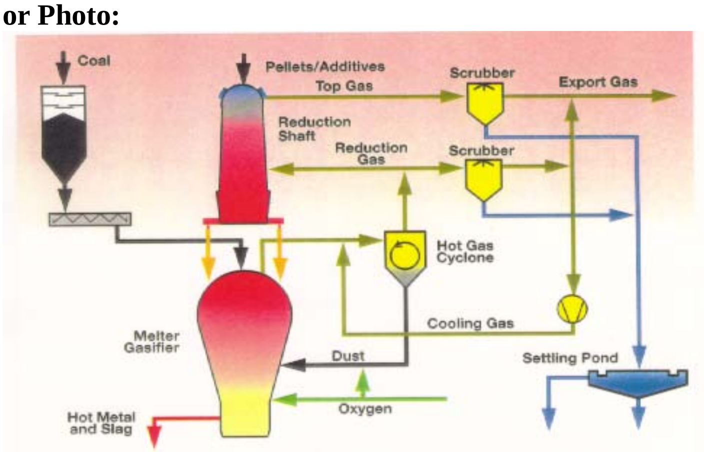


Figure 3.11: Corex Process Simplified Flowsheet

Commercial status: Mature. 5 installations in the world (4 in APP countries)

Contact information: Siemens-VAI

3.2.6 Finex Process

Description:
The FINNEX process is a multistage smelting-reduction process. Its core plant consists of the following: A Melter-Gassifier (MG), which melts the DRI and gassifies the coal; A train of successive fluidised beds that reduce ore fines to DRI.

The fluidized beds represent a counter flow system where ore fines are reduced in 4 stages to DRI. The fines enter each fluidized bed through a lock-hopper system, and descend into the bed that forms on top of a permeable grid. It is then reduced until it is periodically extracted through a riser to the next stage. The DRI product that exists R4, is compacted (plated) and transferred to the MG (Fe (met)~80%). The reducing gas enters each fluidised bed stage from the bottom, flows through the permeable ceramic grid. The fresh reducing gas from the MG enters the first stage (R1) at approximately 800 °C and then progresses through each stage, systematically losing heat until it exists R4 at approximately 550 °C. The MG completes reduction and melting of the DRI. It consists of a fluidized bed resting on a liquid slag and hot metal bath. Coal is pneumatically injected into the MG and charred in the fluidized bed. Oxygen is injected via tuyeres around the circumference of the MG. It forms a raceway, where the oxygen reacts with charred coal to form carbon monoxide. Stable operation requires briquetted coal or coke to be added to the coal mix to carburize the hot metal bath.

For optimum energy efficiency the process requires the following auxiliaries: 1) CO2 stripping of the shaft top gas enables better utilization of the process gas. After CO2 stripping the rich gas is recirculated to the reduction fluidized bed. 2) Cogeneration of the export gas is required due to its high calorific value. 3) PCI injection is required to improve melting capacity of the MG

Energy/Environment/Cost/Other Benefits
- No need for pelletizing, sintering or agglomeration of iron bearing materials
- Possibility to use fine concentrates
- Environmental benefits compare to blast furnace route
- Usage of low quality coals

Block Diagram or Photo:

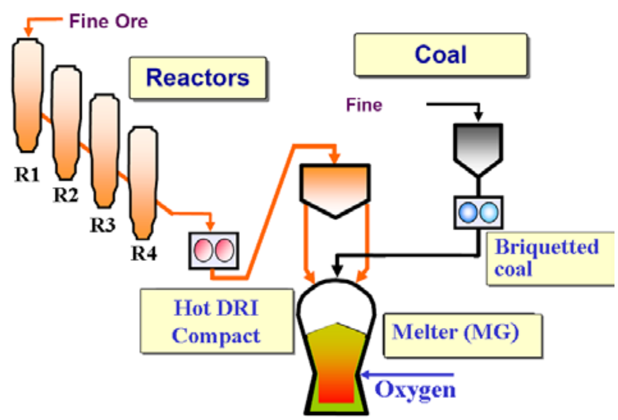


Figure 3.12: Finex Process Simplified Flowsheet

Commercial status: One 1.5 million tonne per annum plant is in operation at Posco, Korea

Contact information: Posco, Korea, Siemens-VAI

3.2.7 Rotary Kiln Direct Reduction

Description:

The rotary Kiln is a rotating cylindrically shaped reactor of 3-6 m diameter and ~ 85 m length installed at an incline. The capacity of the kiln depends on metallization degree and does not exceed 225,000 – 300,000 t/annum. The coal consumption is about 800 kg/t DRI. It is operated in counter-current flow with solids moving down the incline in opposite direction to the gases. Iron ore and coal are jointly charged to the kiln from the charge end. As the burden progresses down the slope it is heated up by the gas to a temperature of 1000-1100 °C. A typical retention time of 10-14 hrs, allows for the ore to be reduced to sponge iron (DRI) by carbon monoxide generated by reaction of carbon with CO_2 inside the burden. Combustion air is supplied by a series of evenly distributed air fans along the kiln through air ducts to the axial area of the kiln, as well as through the discharge end, to burn carbon monoxide and volatiles in freeboard of the kiln to provide necessary heat. The pulverized coal/natural gas/oil burner is installed at the discharge end of the kiln.

The product from the kiln consists of char and sponge iron (DRI). Metallization varies from 83-92% and carbon does not exceed 0.5%. Sponge iron is discharged from the kiln at approximately 800 -1000°C. Low metallization generally is attributed to the rotary kiln operated with electrical smelters for pig iron or hot metal production. In this case hot sponge iron and char are charged directly to smelter. High metallization reflects sponge iron production for EAF steelmaking. In this case hot sponge iron and char are discharged to the rotary cooler, cooled there and after that magnetically separated from each other. Cold sponge iron is transported to the meltshop, while char is recycled back to the process. Off-gases from the smelter and kilns contain sensible and chemical heat. This energy must be recovered by waste heat boilers and co-generation facilities to reduce the coal rate and improve energy efficiency.

Energy/Environment/Cost/Other Benefits

- Low capital cost
- No need for pelletizing, sintering or agglomeration
- Usage of low quality coals
- Significant CO2 and particulate matter emissions are limitations

Block Diagram or Photo:

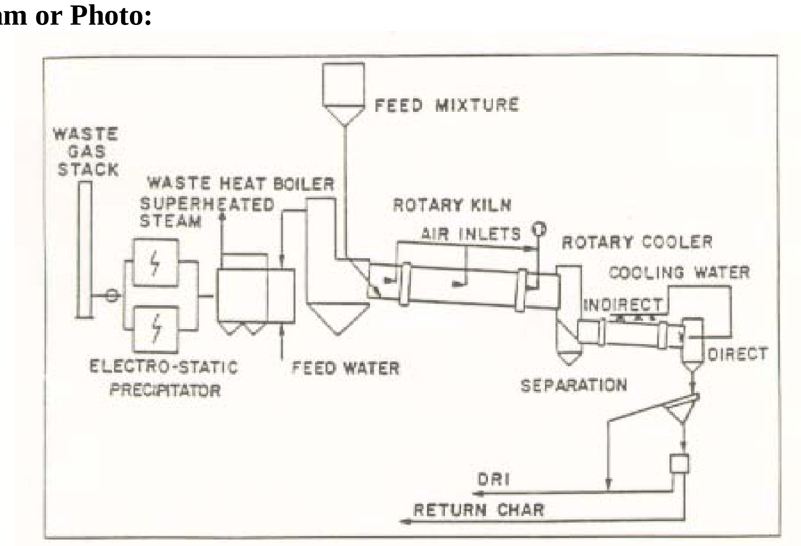


Figure 3.13: SL/RN Rotary Kiln for Sponge Iron Production

Commercial status: Mature
Contact information: Outokumpu – Lurgi

3.2.8 Coal Based HYL Process

Description:
HYL reactor and its peripheral systems and principles of operation are same as gas based HYL process in which oxide material is fed from top and is reduced by a counter current flow of H2 and CO containing gas. Since natural gas is not available for carburization of DRI, lower carbon content of product is expected - . ~0.4 %. Similar to gas based HYL process, furnace top gas is cooled and cleaned and its CO2 is removed and then recycled into reducing gas circuit. Reducing gas is produced in a coal gasifier that can process practically any kind of carbon bearing material. Coal and Oxygen are injected into gasifier and almost all carbon in the coal is gasified. The gas is dust laden and includes CO2 and H2O and other impurities. It is cleaned and cooled in a series of cyclones and H2O, CO2 and Sulphur are removed. Since HYL reactor is designed to work with high H2 content reducing gas, and the gas from gasifier contains considerable amounts of CO, a gas shift reactor is required to convert CO into H2 by the reaction CO + H2O → CO2 + H2

The shift reactor is installed before CO2 removal system. The temperature and pressure of the gas is then regulated before injection into the reactor.

Energy/Environment/Cost/Other Benefits

- No need for coking coal and coke
- No need for natural gas
- Usage of low quality coals
- Production of hot DRI that could be charged to EAF with significant energy savings
- Environmental benefits compare to Blast Furnace route

Block Diagram or Photo:

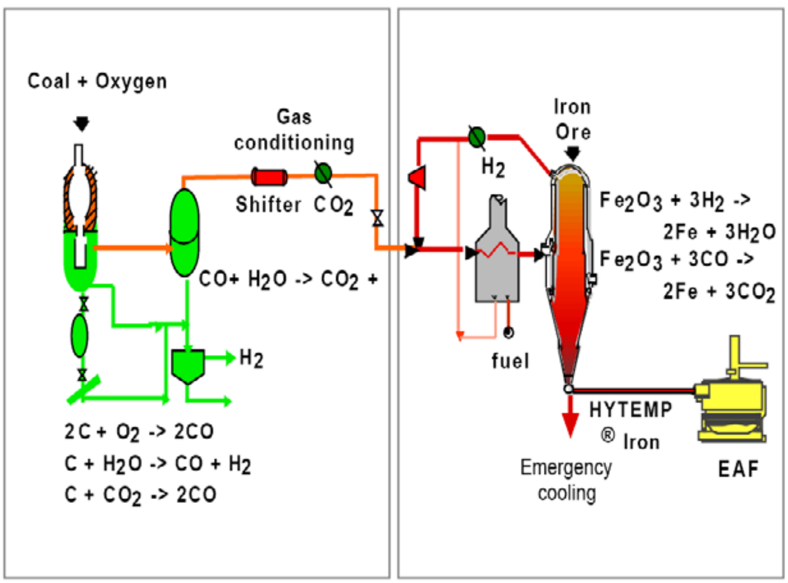


Figure 3.14: Coal Based HYL Process

Commercial status: Emerging
Contact information: Tenova-HYL

3.2.9 Natural Gas Based Zero-Reforming HYL Process

Description:

HYL furnace is a moving bed shaft type reactor operating at relatively elevated pressure of approximately 8 bar. Feed material in the form of pellets and/or lump is charged through a set of pressurizing and depressurizing bins and sealing valves. Iron oxide is reduced by a counter current flow of reducing gas which contains mainly H2 produced by self-reforming of natural gas inside the reactor, where fresh reduced iron plays the role of catalyst. Due to high content of H2, reduction reactions are fast and residence times of 2 – 4 hours are achieved. Natural gas is injected into reducing gas circuit befor the humidifier. Reduced material flows down into a transition zone where most of carburization of DRI takes place. Depending on the type of product, the material continues to flow down into either a cooling zone where it is cooled by a counter current flow of cooling gas to produce cold DRI, or is hot discharged into briquetting machines to produce HBI, or discharges hot into a HITEMP® pneumatic transport system to be directly charged into EAF (HDRI). The product discharges through a set of pressurizing and depressurizing bins and seal valves to keep the reactor high pressure isolated from atmosphere. Spent gas is cooled and cleaned of CO2 and sulphur and recirculated into reducing gas circuit. The process has unique capability to produce DRI with carbon content in the range between 1.5 to 5 %.

Energy/Environment/Cost/Other Benefits

- No need for coking coal and coke
- Lower natural gas consumption compare to reformer base HYL process
- Production of high carbon DRI
- Production of hot DRI that could be charged to EAF with significant energy savings
- Better environmental performance compare ton Blast furnace route and HYL reformer based process

Block Diagram or Photo:

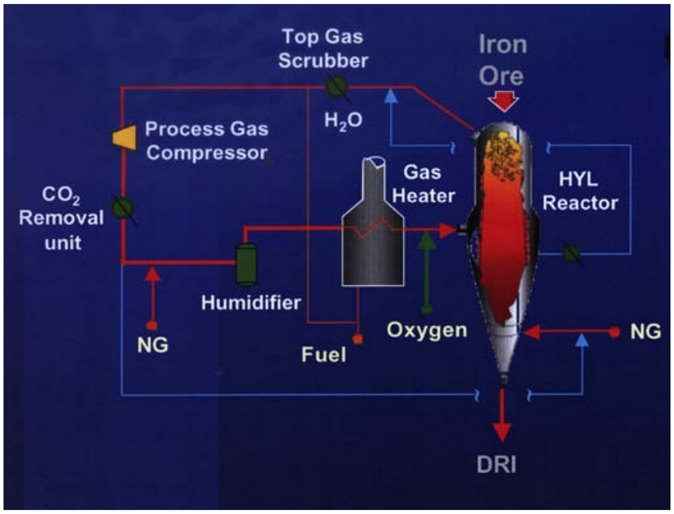


Figure 3.15: Natural Gas Based Zero-Reforming HYL Process for DRI Production

Commercial status: Mature

Contact information: Tenova-HYL

3.2.10 Coal-Based Midrex Process

Description:

Midrex reactor and its auxiliary systems are the same as for gas based Midrex plants. The reactor includes dynamic top and bottom seals and operates at a relatively low pressure of 1.5 barg. Oxide material flows downward by gravity through reduction, transition and cooling zones while product is discharged at a controlled rate from the bottom. Spent gas from shaft furnace is cleaned and cooled in a venturie scrubber and then cleaned from CO2 and H2S in CO2 removal system. Treated gas is recycled into reducing gas circuit, which is produced by coal gasification. Coal gasifier is a high pressure and temperature reactor that gasifies almost all carbon in coal by oxygen. To achieve the (CO + H2)/(CO2 + H2O) ratio > 10 required for reduction process, the gasifier gas should be cooled and cleaned from CO2 .If the gas is delivered at high pressure, a turbo expander unit is installed to throttle its pressure to Midrex operating pressure range. The required ~ 950 ^{0}C temperature of reducing gas is achieved by gas heater and partial combustion with oxygen. Slag produced by gasifier is granulated and can be sold as a by-product.

Energy/Environment/Cost/Other Benefits

- No need for coking coal and coke
- No need in natural gas
- Usage of low quality coals
- Production of hot DRI that could be charged to EAF with significant energy savings
- Environmental benefits compare to Blast Furnace route

Block Diagram or Photo:

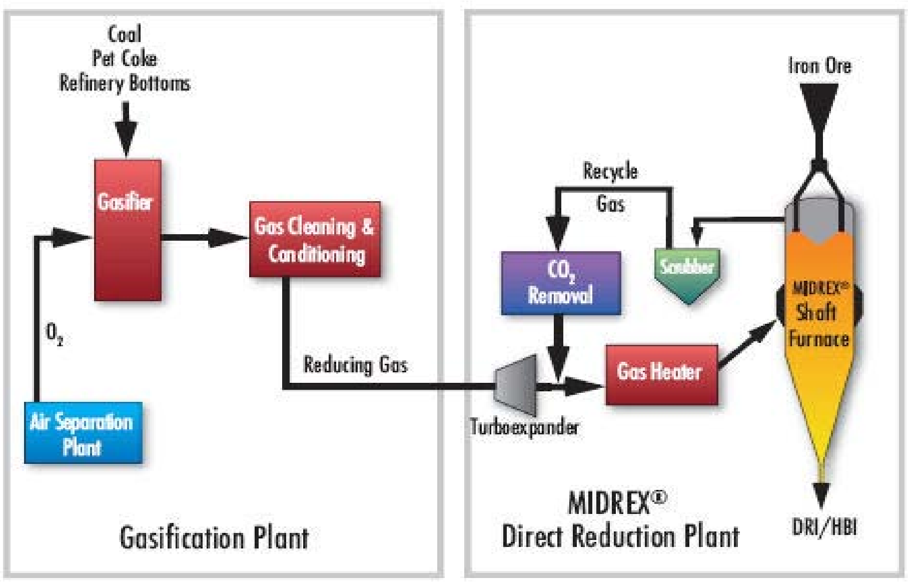


Figure 3.16: Coal Based Midrex Process

Commercial status: Emerging. One prototype operates with reducing gas from Corex melterp-gasifier (Saldanha Steel, ArcelorMittal, South Africa).

Contact information: Midrex

3.2.11 Natural Gas-Based Midrex Process with CO_2 Removal System

Description:

The standard MIDREX Process flowsheet includes a reformer to convert natural gas into a high quality syngas that is used directly for iron ore reduction in a shaft furnace. Traditionally, almost all DR plants with an adjacent meltshop have cooled the DRI and stored it for later charging to the EAF. This option has considerably lower CO_2 emissions than the BF/BOF route. Carbon emissions can be further reduced by discharging DRI hot from the shaft furnace, transporting it to the meltshop, and charging it to the EAF at 600-700º C (see Figure A). This can be done using gravity (HOTLINK®), a hot transport conveyor, or hot transport vessels. All three methods lower the electricity required per ton of steel produced, which also reduces CO_2 emissions from the power plant.

Although the standard MIDREX flowsheet plus EAF enables a decrease of about 50 percent in steelmaking CO_2 emissions versus the blast furnace/BOF, some steelmakers desire greater reductions. Midrex has developed a new concept, shown in Figure B (see below), employing a CO_2 removal system that allows for even lower emissions. This option uses an amine-type system that removes CO_2 from the top gas. This stream is then preheated, with part of it added to the reformed gas, which goes to the shaft furnace. The remainder is used for top gas fuel in the reformer burners. Figure 3 shows a cold DRI plant, but this scheme can also be employed for hot DRI.[32]

Energy/Environment/Cost/Other Benefits

The electricity savings occur because less energy is required in the EAF to heat the DRI to melting temperature. The rule-of-thumb is that electricity consumption can be reduced about 20 kWh/t liquid steel for each 100º C increase in DRI charging temperature. Thus, the savings when charging at over 600º C are 120 kWh/t or more. With the use of hot charging, the DR/EAF route becomes even more attractive.

The DR/EAF route using 80 percent DRI and 20 percent scrap, which is a typical ratio in natural gas-rich areas, has significantly lower carbon emissions than does the BF/BOF method. If the DRI is allowed to cool and then charged to the EAF (CDRI), the emissions are 42 percent less. The use of hot DRI (HDRI) provides even greater savings of 47 percent.

The advantage of CO_2 removal system is that the stack CO_2 emissions per ton of DRI are reduced by 250 kg/t DRI, about 50 percent. The removed CO_2 can be used for enhanced oil recovery, sequestered underground, or sold into a pipeline. For a new facility, capital cost is estimated to increase by five to ten percent versus the standard plant. Natural gas use drops five percent and the electricity consumption increases by 20 kWh/t DRI. Midrex expects that in most cases, this will result in a net decrease in operating cost.

[32] This section is excerpted from: Kopfle, J.T. and Metius, G.E., Environmental Benefits of Natural Gas Direct Reduction. Direct from Midrex, 2nd Quarter, 2010. Available at http://www.midrex.com/uploads/documents/DFM2ndQtr2010.pdf

Block Diagram or Photo:

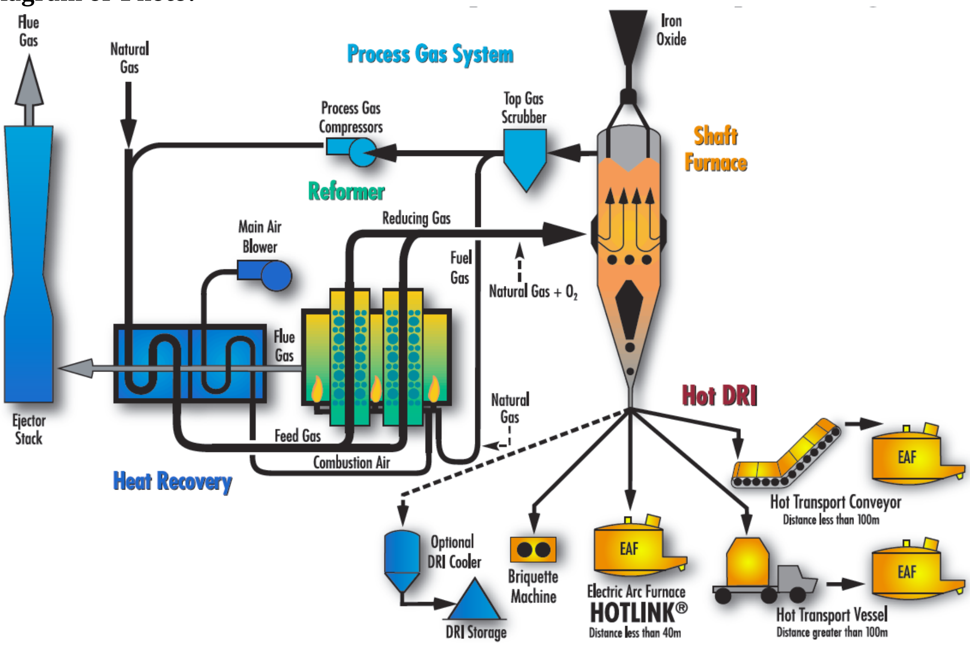


Figure 3.17: NG-based Midrex process with Hot Discharge/Transport/Charging Options

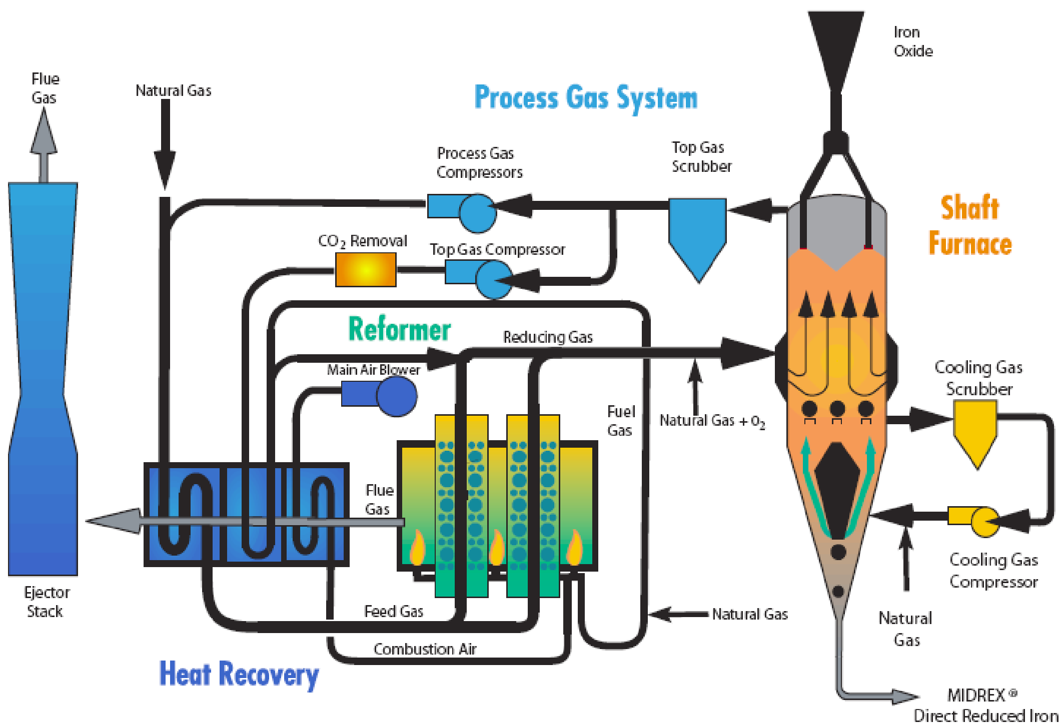


Figure 3.18: NG-based Midrex process with MIDREX Process Low CO_2 Option

Commercial status: mature

Contact information: Midrex

4 Steelmaking

4.0.1 MultiGas™ Analyzer - On-line Feedback for Efficient Combustion[33, 34]

Description:
The MultiGas™ analyzer improves continuous emissions monitoring (CEM) and on-line process tuning of combustion-dependent systems, such as boilers, turbines, and furnaces. The new multi-gas analyzer technology combines advanced Fourier transform infrared spectroscopy with advanced electronics and software. This portable compact system provides real-time measurements and on-line feedback for operational tuning of combustion-based industrial processes. It measures criteria and hazardous air pollutants that are not typically monitored on-site in real-time, such as formaldehyde and ammonia.

Energy/Environment/Cost/Other Benefits:
- Potentially lowering CEM operational energy use by 70%
- Lower operation costs - reduces maintenance and performance verification time, resulting in labor savings of up to 80%.
- Achieves higher combustion efficiency
- Reduces emissions

Block Diagram or Photo:

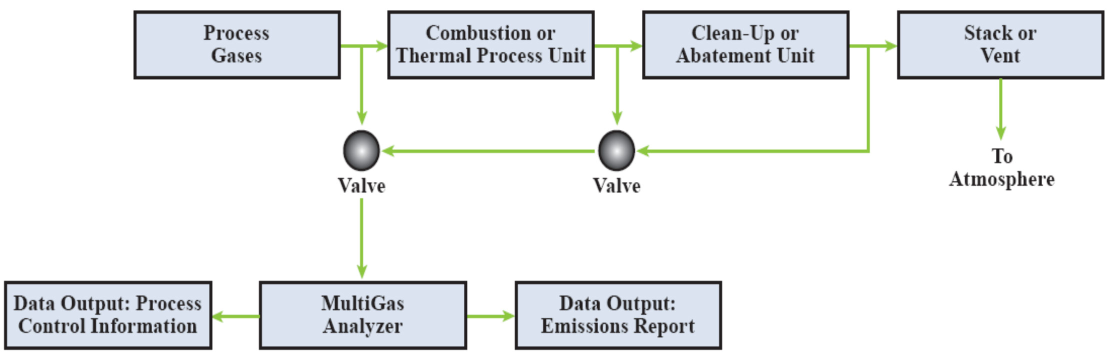


Figure 4.1: Overview of MultiGas™ analyzer system

Commercial Status: Mature

Contact Information:
MKS Instruments, Inc
http://www.mksinst.com

[33] Industrial Technologies Program, Impacts, February 2006, p.71
[34] MKS Industrial product information

4.0.2 ProVision Lance-based Camera System for Vacuum Degasser - Real-time Melt Temperature Measurement[35]

Description:

The lance-based fiber-coupled optical pyrometer measures melt temperature in a vacuum degasser, used for producing ultra-low carbon steel through ladle treatment operation. Temperature control in the ladle is crucial to downstream processes, especially in the continuous caster. To produce desired grades of steel, process models based on melt temperature and chemistry measured after tapping from the iron conversion vessel (BOF, Q-BOP or EAF) and the ladle treatment station are used to determine degassing duration, amount of additional additive (if any), and amount of oxygen blowing. The pyrometer eliminates manual or robot-operated thermocouples. It measures melt temperature automatically before and after oxygen blowing.

Energy/Environment/Cost/Other Benefits:

- Reduction in process time, enabling additional heat of steel per day and increased production value. As with Laser Contouring System (LCS), the primary benefit is reduced processing time. Assuming 1 minute per heat, 48 minutes heat time, and 16 heats per day, this savings results in 0.33 extra production capacity per day. Assuming a 330 day production year and $40 per tonne profit yields an annual profit increase of $0.870 Million.
- Reduction of energy use due to reduced processing time
- Potential emission reductions per installation per year:
  - 550 tons CO_2
  - 2.5 tons NO_2
  - 5.3 tons SO_2
  - 1.93 tons PM

Block Diagram or Photo:

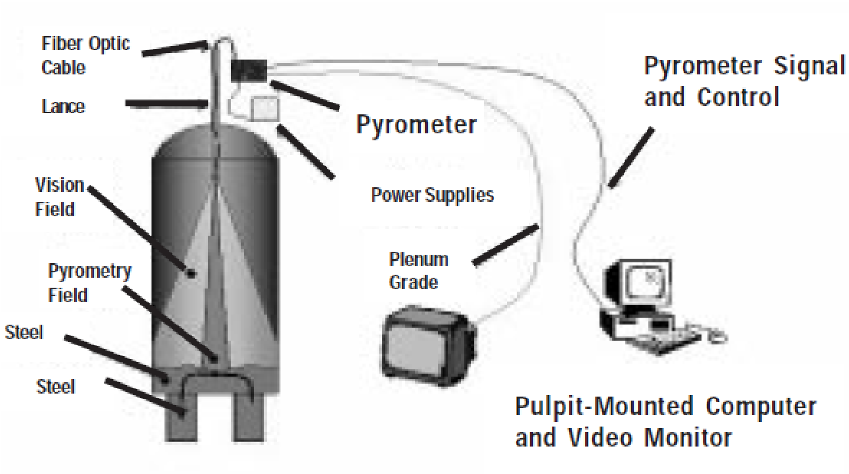


Figure 4.2: Process schematic of optical pyrometer

Commercial Status: Mature

Contact Information:

Process Metrix www.processmetrix.com

Installation information:

Granite City Works plant of United States Steel in Granite City, IL, U.S.

[35] AISI fact sheet #0034, available at http://www.steel.org.

4.0.3 Hot Metal Pretreatment

Description:
Hot metal pre-treatment comprises one or more of the following process steps:

- Desulphurisation (De-S)
- Dephosphorisation (De-P)
- Desiliconisation (De-Si)

The De-S process has been widely adopted by steel companies to reduce the sulphur content of hot metal for the BOF process. The common De-S agents include calcium carbide, lime and magnesium impregnated materials. The use of mixtures of calcium carbide, magnesium and lime allows the hot metal to be De-S to final levels below 0.005%, regardless of the initial sulphur content. Hot metal De-S process can be carried out by a number of different methods and systems. In the more common variants, De-S takes place in the blast furnace launder / pouring stream, in torpedoes as well as in transfer ladle before steelmaking. The known De-S equipment includes the immersion lance for injecting the compounds into the hot metal in the ladle. The compounds are added in powdered form in a carrier gas via the immersed lance. At the end of the De-S process, the slag generated is skimmed-off with the help of a raking machine.

The De-P and De-Si are not as common as the De-S because it involves costly and sophisticated process technology. The common way of De-Si and De-P involves injection of fluxing and oxidizing compounds into the torpedo ladles or hot metal transfer ladles. Several Japanese steel companies have also implemented special De-Si / De-P processes utilizing the BOF convertors. Slag is separated after treatment and removed to avoid reversion.

Energy/Environment/Cost/Other Benefits:

Blast Furnace Ironmaking

- reduced fuel consumption
- reduced flux consumption
- increased output of hot metal and yield
- reduced slag generation

Steelmaking

- Reduced flux and oxygen consumption at steelmaking
- Reduced reblow rates
- Higher steelmaking yield
- Reduced tap-to-tap time
- Reduced need for liquid steel desulphurization at ladle metallurgy facility (lower power consumption, shorter treatment time, lower flux consumption)
- Improved life of refractory lining
- Improved business case with respect to producing higher quality steel grades – line pipe, IF, tinplate, tire cord etc.

Block Diagram or Photo:

There are a number of configurations of hot metal pretreatment, depending on the requirements in a plant.
Figure below shows an example of processing steps employed for De-Si and De-P of hot metal.

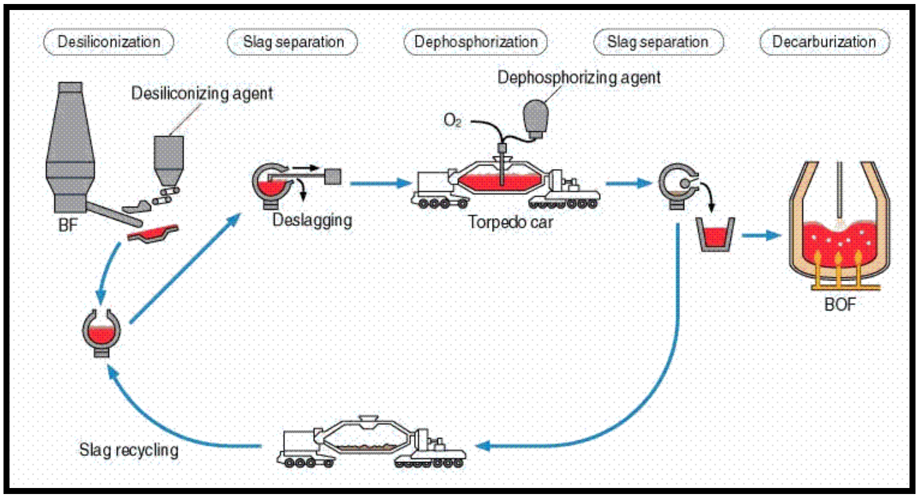


Figure4.3 : Example of Processing Steps Employed for De-Si and De-P of Hot Metal

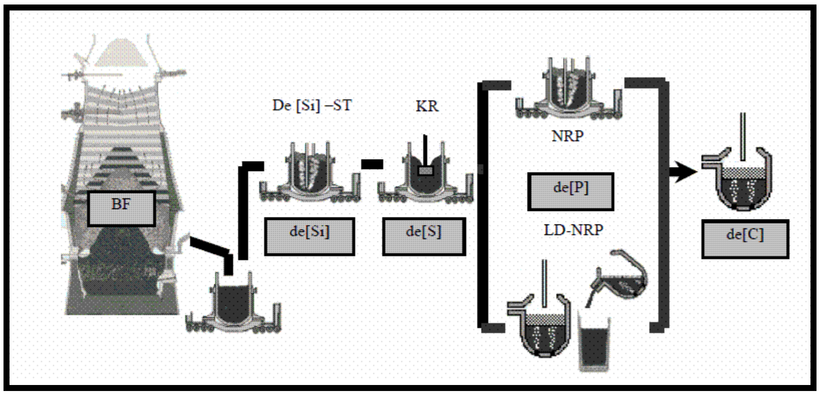


Figure4.4: ZSP (Zero Slag Process) Which Employs All the Three Pretreatment Steps[1].

This process was developed and implemented at NKK's Fukuyama Works is - NRP is ladle-based De-P and LD-NRP is De-P based in LD convertor; the KR process shown is a mechanical-stirring type De-S process.

Commercial Status:
De-S process of all types is quite widely adopted by steel plants; however, the De-Si and De-P processes, although mature and less widely implemented.

Contact Information:

De-S KR Process (mechanical stirring)- Nippon Steel,
De-S Injection Process – Thyssen Bottom Metallurgy, Kuttner, SMS- Siemag, Siemens-VAI
De-Si / De-P – NSC, Kawasaki, NKK

References:
[1]NKK Technical Review, No.88 (2003), pp.18-27

4.1 BOF Steel making

4.1.1 Increase Thermal Efficiency by Using BOF Exhaust Gas as Fuel

Description:
BOF gas and sensible heat recovery (suppressed combustion) is the single most energy-saving process improvement in this process step, making the BOF process a net energy producer. By reducing the amount of air entering over the converter, the CO is not converted to CO_2. The sensible heat of the off-gas is first recovered in a waste heat boiler, generating high-pressure steam. The gas is cleaned and recovered.

Energy/Environment/Cost/Other Benefits:

- Energy savings vary between 535 and 916 MJ/ton steel, depends on the way in which the steam is recovered[36]; with increased power of 2 kWh/ton the total primary energy savings is 136%
- CO_2 reduction of 12.55 kg C per ton crude steel
- $20/ton crude steel investment costs and increased operations and maintenance costs[37, 38]
- Significant reduction of CO and PM emissions, as well as dust which can be recycled in the sinter or steel plant[7, 39]

Block Diagram or Photo:
None provided

Commercial Status: Mature

Contact Information:
None provided

[36] Stelco, 1993. Present and Future Use of Energy in the Canadian Steel Industry, Ottawa, Canada: CANMET.
[37] Inoue, K., 1995. "The Steel Industry in Japan: Progress in Continuous Casting," in *Energy Efficiency Utilizing High Technology: As Assessment of Energy Use in Industry and Buildings*, Appendix A: Case Studies, by M.D. Levine, E. Worrell, L. Price, N. Martin. London: World Energy Council.
[38] Worrell, E., J.G. de Beer, and K. Blok, 1993. "Energy Conservation in the Iron and Steel Industry," in: P.A. Pilavachi (ed.), *Energy Efficiency in Process Technology*, Amsterdam: Elsevier Applied Science.
[39] International Iron and Steel Institute. 1998. "Energy Use in the Steel Industry." September. Brussels, Belgium: International Iron and Steel Institute.

4.1.2 Use Enclosures for BOF

Description:
BOF enclosures operate by covering mixer shop filling, mixer pouring, de-slagging station, converter charging, converter tapping and bulk material handling system on BOF top platform. On the charging top side, a dog house enclosure captures secondary fumes generated during charging. Rectangular high pick-up velocity suction hoods above charging side are connected to duct lines below the operating platform. Suction hoods capture dust during tapping operations above the receiving ladle. Deflector plates guide fumes towards suction hoods. Below the operating platform is a header duct that connects to a centralized fume extraction system of electrostatic precipitators, fans and a stack. Capacity varies between 1,000,000 m^3/h to 2,600,000 m^3/h, depending on heat capacity and operating sequence. Space can sometimes be a limited factor for this technology.

Energy/Environment/Cost/Other Benefits:
- Better working conditions in terms of temperature and dust control
- Visibility of steel making operation and safety improves
- Accumulation of dust over building roofs can be avoided
- Collected dust can be recycled in steel plant

Block Diagram or Photo:

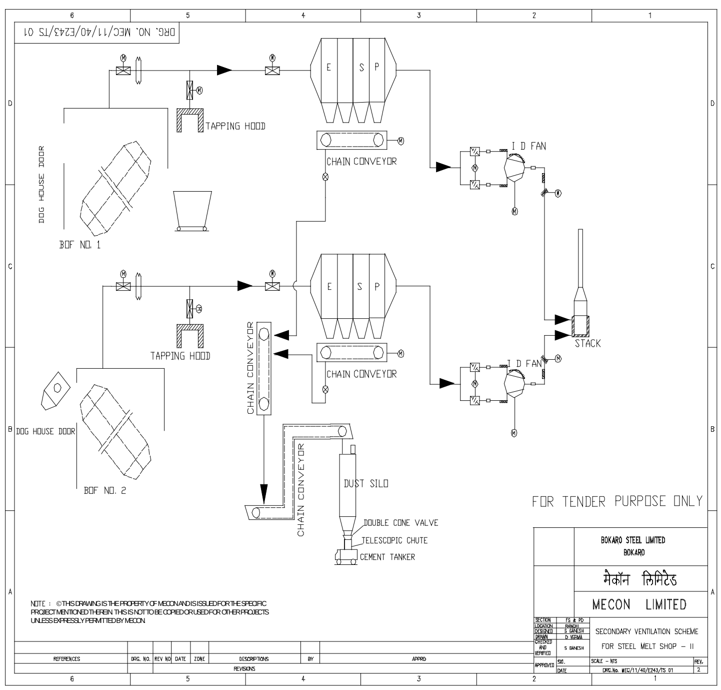


Figure 4.5: Sketch with two converters enclosed

Commercial Status: Mature

Contact Information:
Consultant: MECON Ltd., Ranchi, India
ranchi@mecon.co.in

Suppliers:
SMS Siemag -Delhi
VAI-Siemens Alstom Project, Kolkata, India,

Installation Information:
TISCO

4.1.3 Control and Automization of Converter Operation

Description:
As converters have become larger, operational control and automatic operation have been promoted with various advantages, which are discussed below. Along with the advancement of processing computers and peripheral measuring technology, blowing control for converters has shifted from a static control system to a dynamic or fully automatic operational control system. Indirect measurement of the exhausted gas method is employed in Europe and the United States, whereas direct measurement by the sublance method – direct measurement of the temperature of molten steel simultaneously during blowing – is employed in Japan. Sublance is used for bath leveling, slag leveling, measurement of oxygen concentration and slag sampling.

Energy/Environment/Cost/Other Benefits:
- Increase productivity and product quality
- Decreased labor
- Improved working environment

Block Diagram or Photo:

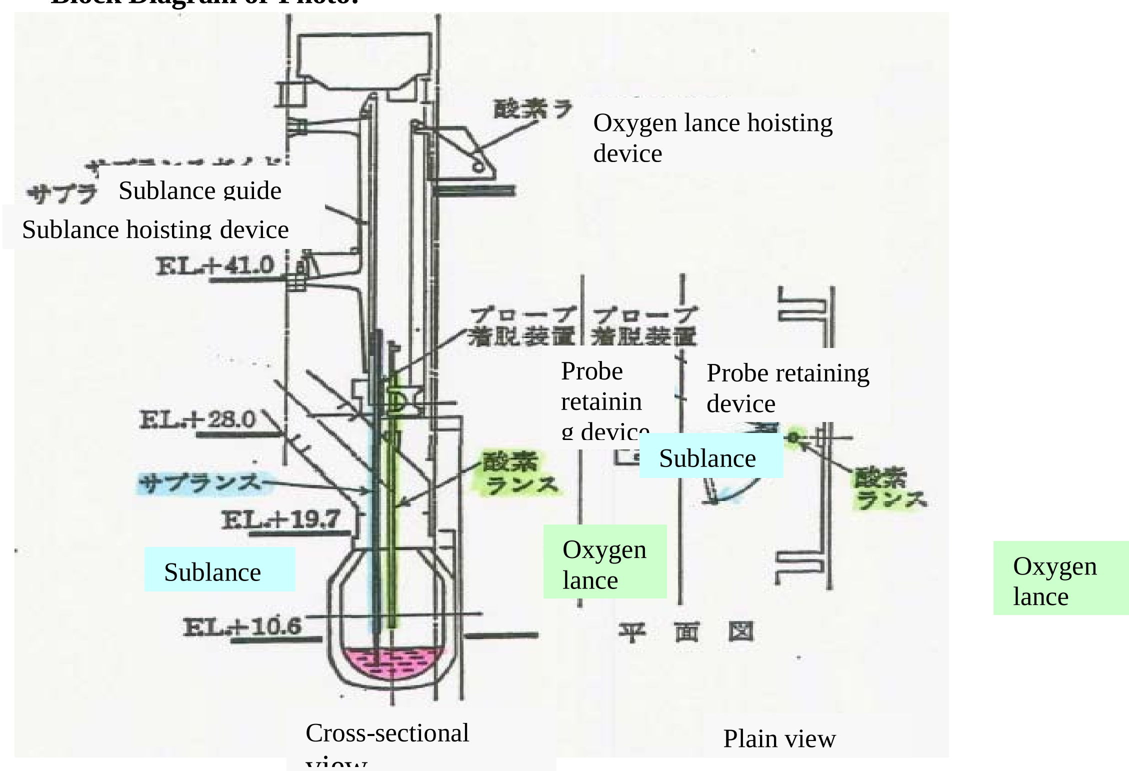


Figure 4.6: Overview of sublance equipment

Commercial Status: Mature

Contact Information:
Nisshin Steel Co., Ltd.
http://www.nisshin-steel.co.jp/nisshin-steel/english/index.htm

4.1.4 Exhaust Gas Cooling System (Combustion System)

Description:
Since steel refining is conducted in a short period of time, about 35 minutes per charge, the dust concentration is very high, usually about 15-25g/m^3N at the inlet of the stabilizer, although in the case of the combustion-type converters, it depends on the amount of combustion air. Dust after the pre-treatment at the stabilizer or first dedusting device is fine grain with a median diameter of 0.2μm, mainly consisting of iron oxide ore. Ingredients of exhaust gas vary along with the process of the converter operation. Combustion-type converters oxidize CO into CO_2 through combustion, in order to prevent an explosion in the smoke duct or treatment equipment. For the purpose of stabilizing such variation, pre-treatment of hot metal is conducted before hot metal is charged into the converter. Exhaust gas treatment consists of an exhaust gas cooling system and a cleaning system. The general combustion-type system is provided with sufficient space between the converter throat and the hood. The second blower sufficiently sends the amount of air that is necessary for CO gas combustion. CO gas is combusted at the hood and the smoke duct into high-temperature gas (1,600^{o}C). The exhaust heat boiler recovers the latent heat and sensible heat of gas as steam through heat exchange.

There are two types of steam recovery boilers, a full boiler equipped with a super heater and coal economizer, and a half boiler without such equipment. The temperature of gas at the boiler outlet is 300^{o}C for full boilers, and about 1,000^{o}C for half boilers. Dust must be removed prior to atmospheric discharge. There are several types of dust removal machines, such as electrical precipitators, venturi scrubbers and bag filters. Among them, electrical precipitators are the most popular. There are both wet-type and dry-type electrical precipitators. The dry type is more popular because the wet type has problems with sludge treatment and erosion control.

Energy/Environment/Cost/Other Benefits:
- Dust removal

Block Diagram or Photo:

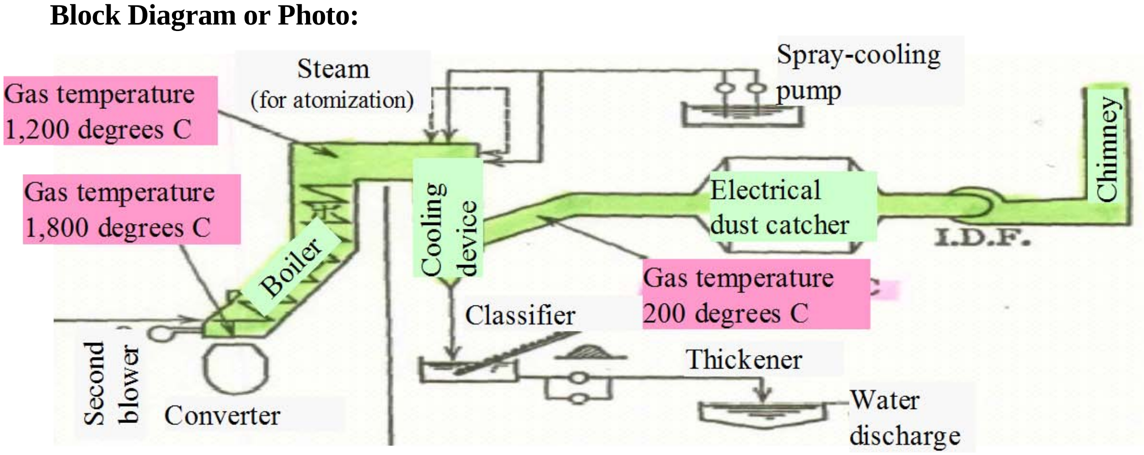


Figure 4.7: Overview of combustion-type system

Commercial Status: Mature

Contact Information:
Nisshin Steel Co., Ltd.
http://www.nisshin-steel.co.jp/nisshin-steel/english/index.htm

4.1.5 OG-boiler System (Non-combustion)/Dry-type Cyclone Dust Catcher

Description:

Since steel refining is conducted in a short period of time, about 35 minutes per charge, the dust concentration is very high. In non-combustion-type converters with a gas recovery function, the dust concentration is 70-80g/m^{3}N at the inlet of the first dedusting device. Non-combustion-type converters, without combusting CO gas, manage the volume of intake air from the throat, and control the concentration to below the explosion limit, thereby recovering CO as fuel. Exhaust gas treatment consists of an exhaust gas cooling system and a cleaning system.

Non-combustion-type systems can be largely divided into the OG-type and the IC (IRSID-CAFL) type. The OG-type system basically has no space between the throat and the hood skirt, and controls pressure at the closed throat. The IC-type system has a gap of several hundred millimeters between the throat and the hood skirt (which has a slightly larger diameter than that of the throat), and controls pressure at the throat opening. The non-combustion-type system keeps gas temperature low and shuts out combustion air; therefore, the cooling device and dedusting device installed in the system are smaller than those installed in the combustion-type system. Since the system handles gas that mainly consists of CO, attention is paid to sealing for the flux and coolant input hole and the lance hole, and leak control at the periphery of devices, as well as purge at the gas retention part. As the volume of converters increases, exhaust gas treatment equipment becomes larger. Large converters adopt the non-combustion-type system for various reasons, such as the relatively small size of the system as a whole, ease of maintenance, and stable dedusting efficiency. The OG-type system is frequently used because of its operational stability. The OG-type cooling system makes it possible not only to recover the sensible heat of exhaust gas as steam, but also to increase the IDF efficiency by lowering the temperature of the exhaust gas by use of a cooling device.

Energy/Environment/Cost/Other Benefits:

- OG-boiler system recovers 65% of the sensible heat of the total exhaust gas, about 70 kg/t
- Increases the IDF efficiency by lowering the temperature of the exhaust gas, achieving high-speed oxygen feeding

Block Diagram or Photo:

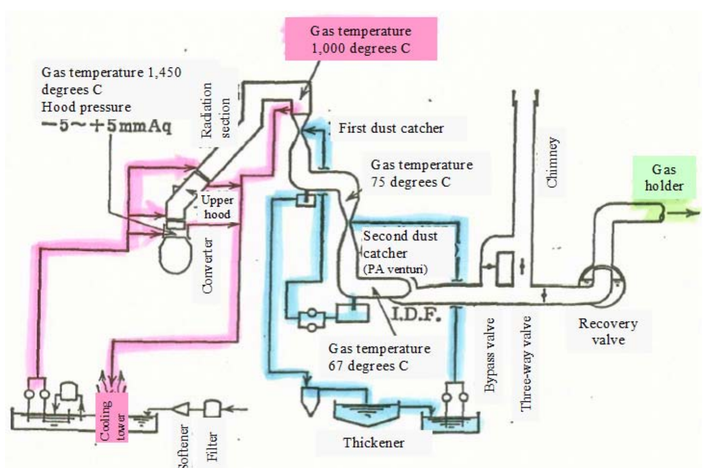


Figure 4.8: Non-combustion OG-type process

Commercial Status: Mature

Contact Information:
Nisshin Steel Co., Ltd. http://www.nisshin-steel.co.jp/nisshin-steel/english/index.htm

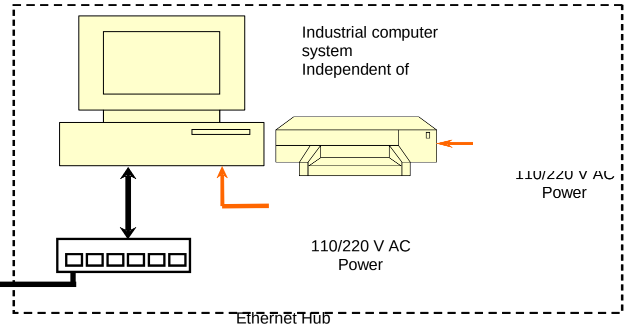
4.1.6 Laser Contouring System to Extend the Lifetime of BOF Refractory Lining[40, 41]

Description:
The Laser Contouring System (LCS) allows rapid measurements of vessel wall and bottom-lining thickness in the steel furnace or ladle environments. The LCS measures refractory lining thickness and incorporates high-speed laser-based distance measuring equipment with a robust mechanical platform and easy-to-use software. With a laser scan rate of over 8,000 points per second, a single vessel scan can include over 500,000 individual contour measurements, providing detailed contour resolution and accurate bath height determination. LCS is available as a mobile platform or a fixed position installation. The LCS maps the entire vessel interior in less than 10 minutes and provides detailed contour resolution and vessel lining thickness with over 500,000 individual contour measurements

Energy/Environment/Cost/Other Benefits:
- Reduce energy usage via rapid real-time measurement and no loss of process time
- Reduction of maintenance on BOF refractory via automated furnace inspection
- Laser Contouring System – Ladles:
  - Conservatively assume a 5% lifetime extension for the ladles in use in each mill. A "standard" mill consumes $3M in ladle refractory per year. Assuming 4M tons/year output, the savings is $0.04/ton. These numbers are approximate, and obviously vary considerably with refractory usage, cost and mill output.
- Laser Contouring System – Converters
  - While there may be some opportunity for savings via reduced refractory usage, the primary advantage arises through increased throughput. The LCS instrument saves 6-15 minutes of production time per day, per vessel. Assuming a 40 minutes heat time, and a median measurement time savings of 9 minutes, this is equivalent to increasing throughput by 0.22 heats per day per vessel. For a two vessel shop, operating 200 ton BOF's, this equates to an increase in production capability of 0.44 heats per day. At $40 per ton profit, this equates to a net profit increase of $3,520 per day or $1.1M (profit) over a 330 day work year.
- No data on environmental benefits, though ladle lifetime extension does create the opportunity for reduced consumption of raw material and refractory landfill usage.

[40] Industrial Technologies Program, Impacts, February 2006, p.61
[41] Process Metrix product information

Block Diagram or Photo:



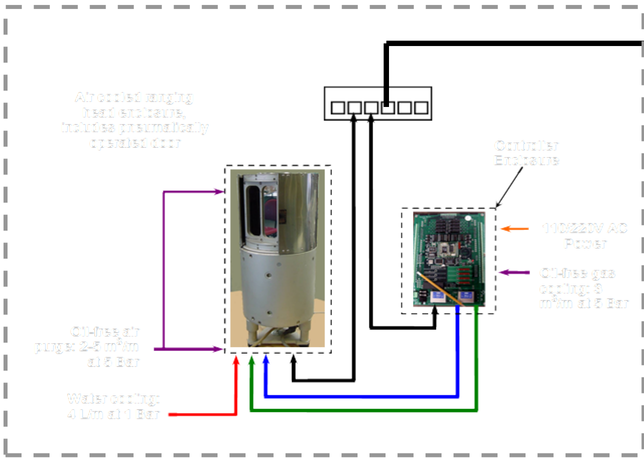


Figure 4.9: LCS layout

Commercial Status: Mature

Contact Information:

Process Metrix www.processmetrix.com

Installation information:

Nucor Steel Corp. plant in Berkeley, SC, U.S.

4.1.7 BOF Bottom Stirring

Description:
One of the major innovations in the BOF steelmaking has been the introduction of small amount of inert gas from the bottom of the convertor to accompany oxygen injection through the top vertical lance. This is referred to as bottom stirring in the BOF (also combined blowing). Depending on the convertor size and the specific requirements of each plant, the BOF steelmaking uses top lance with multi-holes (openings) along with different systems for bottom gas injection. The top lance basically supplies the oxygen and by changing the lance height, distribution of oxygen between the metal and slag can be varied. The injected gas provides mild stirring of the bath during and after top blowing with oxygen. The introduction of the gas promotes a desirable carbon-oxygen equilibrium in the bath and slag, resulting in reduction of slopping. There are a number of systems for injection of inert gas – porous bricks, channeled bricks, canned bricks (in metal casings), ceramic tuyrres etc. There are a number of processes – LBE (lance bubbling equilibrium from Arbed / Irsid), LD-KG (Kawasaki), NK-CB (NKK combined blowing), LD-TBM (Thyssen Blas Metallurge), LD-AB (Argon Blowing from Nippon Steel) etc.
In addition to simple inert gas injection, it is worth mentioning that some BOF convertors have a more advanced injection system in which oxygen, flux and other gases are injected from the bottom of convertor.

Energy/Environment/Cost/Other Benefits:

- Improved BOF yield – less slopping, less iron loss to slag
- Reduced flux and oxygen consumption
- Reduced reblow rate; lower oxygen in steel (less alloy additions)
- Improved vessel life (considering base as – convertor with no slag splashing)
- Provides ability to produce lower carbon steel

Block Diagram or Photo:

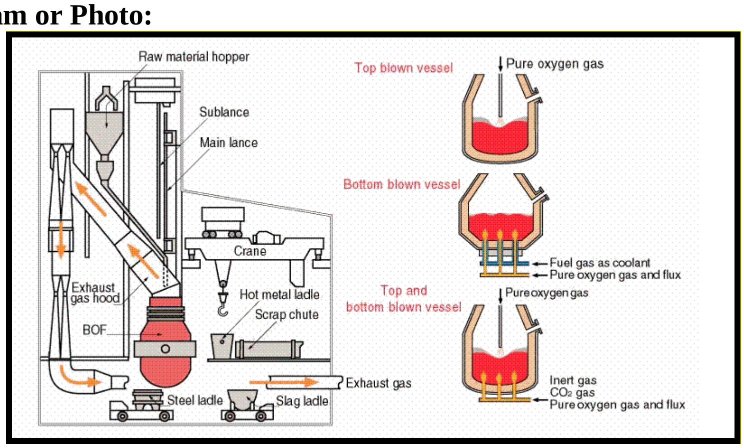


Figure 4.10: Schematic Showing the Top and Bottom Stirring Features for Oxygen Steelmaking

Commercial Status: Mature

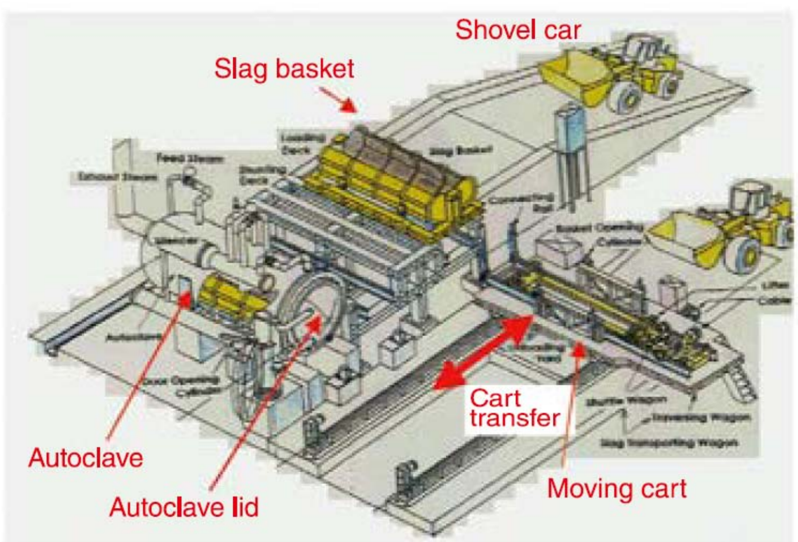
Contact Information:
SMS-Siemag, Siemens-VAI, Refractory Suppliers – RHI, TYK, Steel Companies such as Nippon Steel, JFE, Thyssen, Arcelor-Mittal and others

4.1.8 Pressurization-type Steam Aging Equipment for Steel Slag

Description:
Steel slag, which is generated as a by-product at the time of steel refining, is composed mostly of calcium. Therefore, steel slag hardens when it reacts with water. That is why steel slag is widely used for construction materials, such as roadbeds. The use of steel slag makes sturdy roadbeds that will not be easily rutted, hence ensuring comfortable road traffic and contributing to a reduction of road repair costs.
The volume of the unmelted quicklime (CaO) in steel slag expands when it reacts with water. Therefore, steel slag reacts needs aging processing in which the slag reacts with water or steam before use so that the slag will fully expand. The natural aging of steel slag requires two years. The conventional industrial open yard steam aging of steel slag requires at least two days, and it has some of problems such as the requirement of large aging yards and workforce to protect the slag with covers.
The new technology developed by Sumitomo Metal Industries, Ltd. has attained an increase in the efficiency of aging by allowing the steel slag to react under a pressurized steamy atmosphere, thus making it possible to increase the speed of reaction 24 times more than that of by open yards method. Sumitomo Metal Industries, Ltd. devised a number of streamlining means including the introduction of device to transfer slag buckets automatically by cart into a large-scale pressure container.

Energy/Environment/Cost/Other Benefits:
- Reduction in energy cost
- Reduction in labor cost
- Significant reduction in aging time
- Eliminating the necessity of vast aging yards.

Block Diagram or Photo:



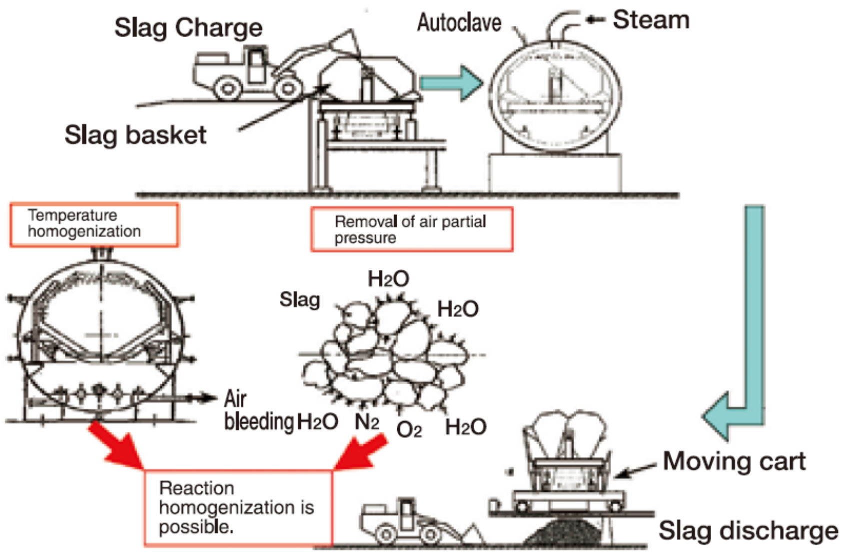


Figure 4.11: Pressurization-type Steam Aging Equipment for Steel Slag

Commercial Status: Mature

Contact Information:
Sumitomo Metal Industries, Ltd.
http://www.sumitomometals.co.jp

4.2 EAF Steelmaking

4.2.1 Elimination of Radiation Sources in EAF Charge Scrap

Description:
Effective radiation control involves a redundant scan process to inspect incoming scrap material for hidden radiation sources.
Purchased scrap may undergo radiation detection by the supplier prior to delivery onsite. All incoming scrap to the facility is passed through the Exploranium AT-900 detection equipment. Scrap flagged as high risk undergoes additional scanning from hand detectors. A second scan with the AT-900 is performed prior to melt shop delivery and a final scan is performed on each magnet load as charge buckets are filled. EAF baghouse detectors define when, if any, radioactive material has been melted.

Energy/Environment/Cost/Other Benefits:
- Reduced radiation

Block diagram or photo:

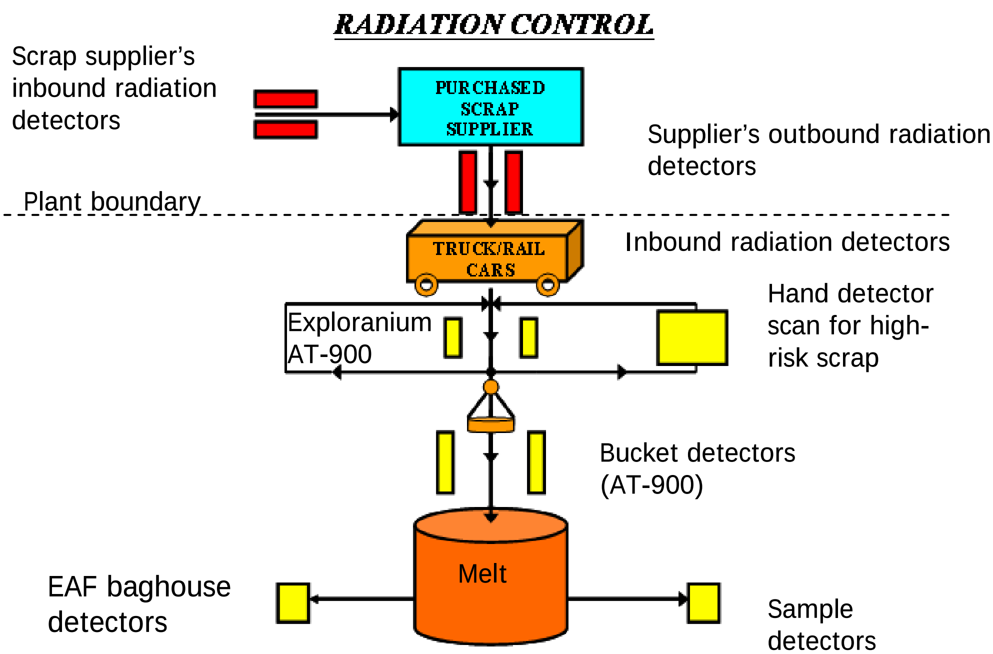


Figure 4.12: Schematic of radiation control process[42]

Commercial Status: Mature

Contact Information:
The Timken Company
www.timken.com

[42] Source: the Timken Company

4.2.2 Improved Process Control (Neural Networks)

Description:
Improved process control (neural networks) can help to reduce electricity consumption beyond that achieved through classical control systems. For example, neural networks or "fuzzy logic" systems analyze data and emulate the best controller. For EAFs, the first "fuzzy logic" control systems have been developed using current power factor and power use to control the electrodes in the bath[43].

Energy/Environment/Cost/Other Benefits[44]:

- Electricity savings of 30 kWh/t steel
- Increase in productivity of 9 to 12%[14]
- Reduced electrode consumption of 25%[14]
- Capital and commissioning costs are about $250,000 per furnace, or about $0.95/t in the U.S.[45]
- Furnace maintenance costs are reduced as well; annual operating costs savings of $1/t steel

Block Diagram or Photo:
None provided

Commercial Status: Mature

Contact Information:
None provided

Installation information:
Ternium Hylsa plant in Monterrey, Mexico.

[43] Staib, W.E. and N.G. Bliss, 1995. "Neural Network Control System for Electric Arc Furnaces" Metallurgical Plant & Technology International 2: 58-61.
[44] The actual savings depend on the scrap used and the furnace operation
[45] Kimmerling, K., 1997. Personal communication and reference list, Neural Applications Corporation, Coralville, IA (26 August 1997).

4.2.3 Oxy-fuel Burners/Lancing

Description:
Oxy-fuel burners/lancing can be installed in EAFs to reduce electricity consumption by substituting electricity with oxygen and hydrocarbon fuels. They reduce total energy consumption because of:

- Reduced heat times, which save 2-3 kwh/ton/min of holding time
- Increased heat transfer during the refining period
- Facilitates slag foaming, which increases efficiency of oxygen usage and injected carbon

Care must be taken to use oxy-fuel burners correctly, otherwise there is the risk is that total energy consumption and greenhouse gases will increase.

Energy/Environment/Cost/Other Benefits:

- Electricity savings of 0.14 GJ/tonne crude steel, typical savings range from 2.5 to 4.4 kWh per Nm^3 oxygen injection[46, 47, 48, 49] with common injection rates of 18 Nm^3/t
- Natural gas injection is 10 scf/kWh ($0.3m^3/kWh$)[50] with typical savings of 20 to 40 kWh/t[51]
- Retrofit Capital Costs of $4.80/t crude steel on an EAF of 110 tons
- Improved heat distribution leads to reduced tap-to-tap times of about 6%[52], leading to estimated annual cost savings of $4.0/t[53]
- Reduction of nitrogen content of the steel, leading to improved product quality[54]

Block Diagram or Photo:

Figure 4.13: Oxy-fuel burner

Commercial Status: Mature, widely used

Contact Information:

American Combustion International	Process Technology	Air Products and Chemicals, Inc.
www.americancombustion.com	www.pticombustion.com	www.airproducts.com

[46] International Iron and Steel Institute, Committee on Technology, 1982. *Energy and the Steel Industry*, Brussels, Belgium: IISI.
[47] Center for Materials Production, 1987. *Technoeconomic Assessment of Electric Steelmaking Through the Year 2000*, EPRI/CMP, Report 2787-2, October 1987.
[48] Haissig, M., 1994. “Enhancement of EAF Performance by Injection Technology” *Steel Times*, October 1994 pp.391-393.
[49] Stockmeyer, R., K-H. Heinen, H. Veuhoff, and H. Siegert, 1990. “Einsparung von elektrischer Energie am Lichtbogenofen durch eine neue Ausqualmregelung” *Stahl u. Eisen* **110**(12): 113-116.
[50] Center for Materials Production, 1992. *Electric Arc Furnace Efficiency*, EPRI/CMP, Report 92-10, Pittsburgh, PA: CMP.
[51] Jones, J. A. T. 1996. "New Steel Melting Technologies: Part III, Application of Oxygen Lancing in the EAF." *Iron and Steelmaker* 23 (6): 41-42.
[52] Center for Materials Production, 1995. *Coal & Oxygen Injection in Electric Arc Furnaces*, Tech Bulletin CMP 95-7TB, CMP, Pittsburgh, PA.
[53] Center for Materials Production, 1987. *Technoeconomic Assessment of Electric Steelmaking Through the Year 2000*, EPRI/CMP, Report 2787-2, October 1987.
[54] Douglas, J., 1993. “New technologies for Electric Steelmaking” *EPRI Journal*, October/ November 1993, pp.7-15.

4.2.4 Scrap Preheating

Description:
Scrap preheating is a technology that can reduce the power consumption of EAFs through from using the waste heat of the furnace to preheat the scrap charge. Old (bucket) preheating systems had various problems, e.g., emissions, high handling costs, and a relatively low heat recovery rate. Modern systems have reduced these problems and are highly efficient. The energy savings depend on the preheat temperature of the scrap. Various systems have been developed and are in use at various sites in the U.S. and Europe, i.e., Consteel tunnel-type preheater, Fuchs Finger Shaft, and Fuchs Twin Shaft. All systems can be applied to new constructions, and also to retrofit existing plants.

4.2.4.A. Tunnel Furnace - CONSTEEL Process

Description:
The Consteel® system is the commercial process that continuously pre-heats and feeds the metallic charge (scrap, pig iron, etc.) into the EAF while simultaneously controlling gaseous emissions. The charge is loaded directly from the scrap yard or the railcar to the charge conveyor, and pre-heated by the furnace off-gas as it is automatically transported to the EAF.

The pre-heated charge is fed into the EAF where it is melted by the liquid steel in a continuous cycle. This permits constant flat bath operation, a key advantage over conventional batch processes where the scrap is melted directly by the electric arc. The EAF gases are sent to a fume-cleaning plant where carbon monoxide and pollutants are burned in a combustion chamber without consuming fuel. The system uses heat from the flue gas for cogeneration of hot water and/or steam.

The Consteel® system technology simplifies steelmaking logistics by minimizing scrap movements. Furnace bay crane activities using charge buckets are virtually eliminated, for lower operating and maintenance costs. Leakages in the water-cooled furnace sidewalls, roof and lances caused by arcing or scrap impact are avoided, thus minimizing the risk of water entering the furnace. Various U.S. plants have installed a Consteel process, as well as one plant in Japan.

Energy/Environment/Cost/Other Benefits Consteel process:
- Productivity increase of 33%[55]
- Reduced electrode consumption of 40%[29]
- Reduced dust emissions by around 30%[56]
- Electricity savings estimated to be 60 kWh/t for retrofits
- Annual operating cost savings of $1.90/t crude steel (including productivity increase, reduced electrode consumption, and increased yield
- Retrofit Capital Costs $4.4 to $5.5/t ($2M for a capacity of 400,000 to 500,000 t/year[57])
- Decrease in the electrical disturbance on the network
- Lower use of scrap and no burner fuel consumption
- 1-2% increase in scrap yield

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[55] Jones, J. A. T. 1997a. "New Steel Melting Technologies: Part X, New EAF Melting Processes." *Iron and Steelmaker* **24**(January)**:** 45-46.
[56] Herin, H.H. and T. Busbee, 1996. "The Consteel® Process in Operation at Florida Steel*"* *Iron & Steelmaker* **23**(2): 43-46.
[57] Bosley, J. and D. Klesser, 1991. *The Consteel Scrap Preheating Process*, CMP Report 91-9, Center for Materials Production, Pittsburgh, PA.

Block Diagram or Photo:

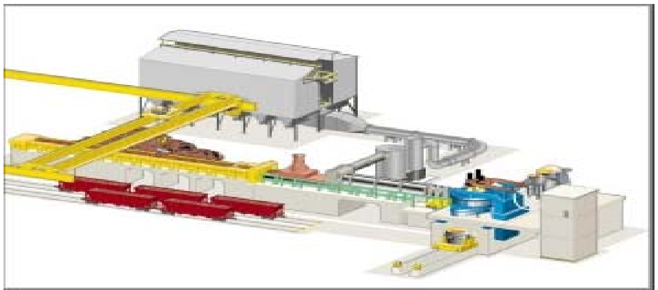

Figure 4.14: CONSTEEL process[58]

Commercial Status: Mature

Contact Information:
Techint Technologies, www.techint-technologies.com
Tenova CORE http://corefurnace.com

Installation information:
Wheeling Pittsburgh Steel plant in Mingo Junction, WV, U.S.

4.2.4.B. Post Combustion Shaft Furnace (SIMETAL^{CIS} EAF Shaft)

Description:
The Siemens VAI shaft furnace consists of a vertical shaft that channels the off-gases to preheat the scrap. The scrap can be fed continuously or through a so-called system of 'fingers'[59]. The optimal recovery system is the 'double shaft' furnace, which can only be applied for new construction. The Siemens VAI-systems make almost 100% scrap preheating possible, leading to potential energy savings of 100-120 kWh/t[60]. Carbon monoxide and oxygen concentrations should be well controlled to reduce the danger of explosions, as happened at one plant in the U.S.

Energy[61]/Environment/Cost/Other Benefits Siemens VAI process:

- Electricity savings of 120 kWh/t and fuel increases of 0.7 GJ/t
- Annual operating cost savings of $4.5/t (excluding saved electricity costs)
- Retrofit Capital Costs of about $6/t crude steel[33] for and existing 100 t furnace
- Reduced electrode consumption
- Yield improvement of 0.25-2%[33, 62]
- Up to 20% productivity increase[33]
- 25% reduced flue gas dust emissions (reducing hazardous waste handling costs)[36]

58Source: http://www.corefurnace.com/meltshop_01.html
59 Siemens VAI, 1997. *FUCHS Shaft Furnaces, The Power, The Performance, The Profit*, Linz, Austria: Voest Alpine Industrieanlagenbau Gmbh.
60 Hofer, L., 1997. Personal communication, Voest Alpine Industrieanlagenbau Gmbh, Linz, Austria, 25 September 1997.
61 The energy savings depend on the scrap used, and the degree of post-combustion (oxygen levels)
62 Center for Materials Production. 1997. *Electric Arc Furnace Scrap Preheating.* Tech Commentary, Pittsburgh, PA: Carnegie Mellon Research Institute.

Block Diagram or Photo:

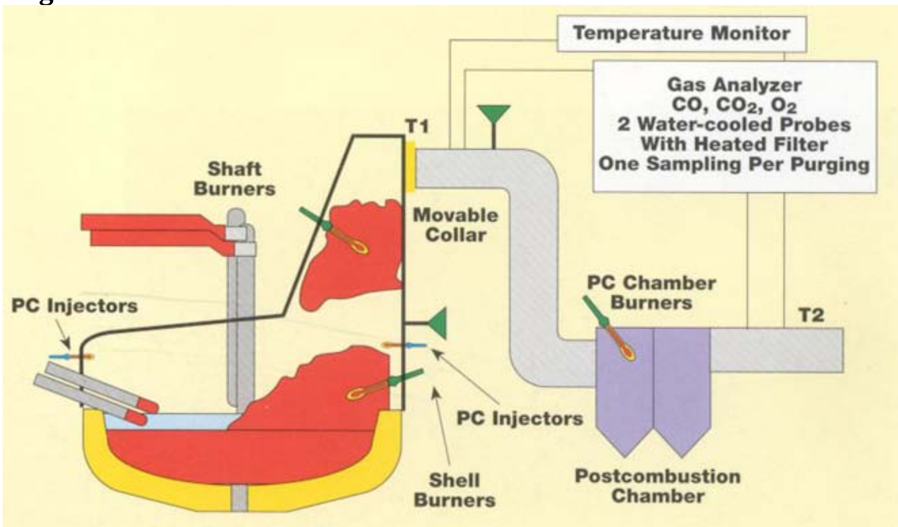

Figure 4.15: Schematic of SIMETAL Shaft Furnace[63]

Commercial Status: Mature

Contact Information:
Siemens VAI, www.siemens-vai.com

Installation information:
Arbed plant in Aristrain, Spain.

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63 Source: http://www.vai.at/view.php3?f_id=1029&LNG=EN

4.2.4.C. Continuous Horizontal Sidewall (CHS) Scrap Charging

Description:
Scrap charging and preheating for the electric arc furnace (EAF) have been used in many forms over the past 30 years. Te majority of steelmakers are using top charging via a bucket as the primary mean of scrap addition. SMS Siemag Inc. has developed the alternative system called Continuous Horizontal Sidewall (CHS) scrap charging. They claim that the common preheating arrangements are typically complex in structure and require a large amount of space and most of them require a great deal of maintenance and also environmental concerns such as offensive odors and the potential for dioxin and furan generation of CO explosion are an issue. Besides, in many cases post-combustion burner is required, so the claims of net energy benefit is questioned, especially when the electricity use for pumping and cooling towers to supply the increased cooling water usage is considered. SMS Siemag Inc. claims that CHS scrap charger provides all the benefits of a scrap preheater without the aforementioned problems. In essence, it is most like a scrap baler or logger except the end open to the furnace is unconstrained so the scrap is uncompressed and permitted to fall into the furnace.[64]

Energy/Environment/Cost/Other Benefits:
Some of the aspects of CHS scrap charger are listed by SMS Siemag Inc. as:

- Lower energy consumption by eliminating opening the roof.
- Combustibles in the scrap burn in the furnace; adding to the energy input of the furnace.
- After-burners are not required which further add to the overall efficiency of the process.
- Flat bath operation eliminates scrap cave-ins that cause electrode breakage.
- Flat bath operation result in a consistent foamy slag to enhance efficiency and prevent nitrogen pickup.
- Reduce furnace idle time results in less electrode oxidation and lower consumption
- Shorter tap-to-tap times result in lower losses and resultant power use.
- Scrap sizing requirements are less restrictive for lower overall production costs.
- Lower refractory consumption due to less mechanical damage and thermal shock.

Block Diagram or Photo:

None provided

Commercial Status: Emerging

Contact Information:
SMS Siemag Inc. http://www.sms-siemag.de

[64] This section excerpted from: Cotchen, J.K. and Stercho, M.J., 2002. Continuous Horizontal Sidewall (CHS) scrap charging. Available at http://cat.inist.fr/?aModele=afficheN&cpsidt=14418054

4.2.5 New scrap-based steelmaking process predominantly using primary energy

Description:
The major type of energy used in EAF is the electricity. The primary energy source is first converted to heat in a power station, producing electrical energy in the next step. These two conversion processes, like all other conversions, entail losses whose amount is determined by the efficiency of the power station. In state-of-the art power stations this efficiency is no higher than 40 to 42%. The electrical energy produced is transported to the EAF, whereby further losses are incurred, and then converted back to heat for steelmaking. If almost two thirds of the original primary energy is lost on the conversion route from source to EAF, there should be a way to use this energy directly on site in the form of heat. The efficient use of primary energy in the heating and melting steps should be possible in a counter-current reactor. In a reactor designed in this way, the scrap to be molten is continuously charged at the top and transferred to the liquid state with tapping temperature roughly above liquidus by the combustion of fossil fuels with oxygen. Since it is physically impossible to significantly superheat the melt in the presence of solid material superheating occurs in a separate vessel by electricity. Thus, it can be said that whereas the conventional EAF separates melting and heating in terms of time, these steps are separated spatially in the primary-energy melting process. The melting vessel here is a countercurrent reactor as stipulated above, and the superheating vessel is an electric arc furnace with a power requirement comparable to that of a ladle furnace (figure below).[65]

Energy/Environment/Cost/Other Benefits:
About 32% reduction of primary energy intensity for liquid steel production compared to the conventional EAF. Depending on the CO_2 emission of the electricity grid, the significant amount of CO_2 emission will also be reduced. About 19% reduction in the energy cost per tonne of liquid steel produced.

Block Diagram or Photo:

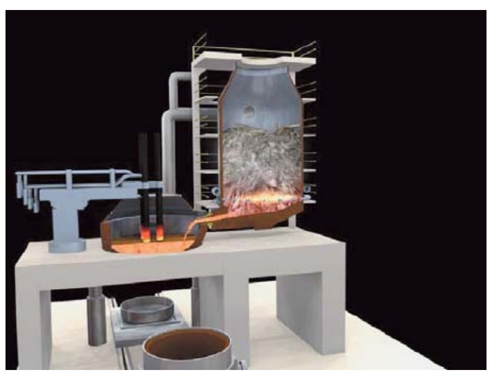

Figure 4.16: Schematic of the primary energy melter

Commercial Status: Emerging

Contact Information:
SMS Siemag Inc. http://www.sms-siemag.de

[65] This section excerpted from: Falkenreck, U., 2007. New scrap-based steelmaking process predominantly using primary energy. MPT International 3/2007

4.2.6 Hot DRI/HBI Charging to the EAF

Description:

Over the last number of years the use of DRI and/or HBI as a charge material has increased substantially with global production now in excess of 65 million tons per annum. In recent years the majority of captive DRI production units installed have been focused on charging of Hot DRI/HBI to the EAF at temperatures in the range of 600 °C. The majority of global DRI production is processed using natural gas based reduction units but a small fraction is produced using coal based processes.

The hot DRI charge practice utilizes the same basic reduction units as are used in cold DRI melting, however, the cooler unit at the bottom of the reactor which allows material discharge at temperatures in excess of 600 °C. The Hot DRI can be transferred to the EAF using one of 4 methods:

- Pneumatic transportation
- Electro-mechanical conveyor transport
- Gravity feed from an elevated reactor
- Transport in insulated bottles using mobile equipment

Pneumatic and electro-mechanical transport require that the DRI reactors be built adjacent to the steelmaking furnace to minimize the transportation distance of the material. In the gravity feed system the reduction unit is built as close as possible to the EAF and elevated 20 to 30 m above the furnace to allow direct gravity feed in operation. With the bottle transfer system the DRI reactors are located some distance from the melting furnace.

Charging hot DRI at temperatures up to 600 °C rather than cold DRI results in a melting energy reduction of 150 kWh/t of crude steel (>0.5 GJ/ton).

Energy/Environment/Quality/Cost Benefits:

- Energy Reduction
- Increased Productivity
- Decrease in tramp element content
- Improved slag foaming
- Increased carbon content in the charge

Block Diagram or Photo:

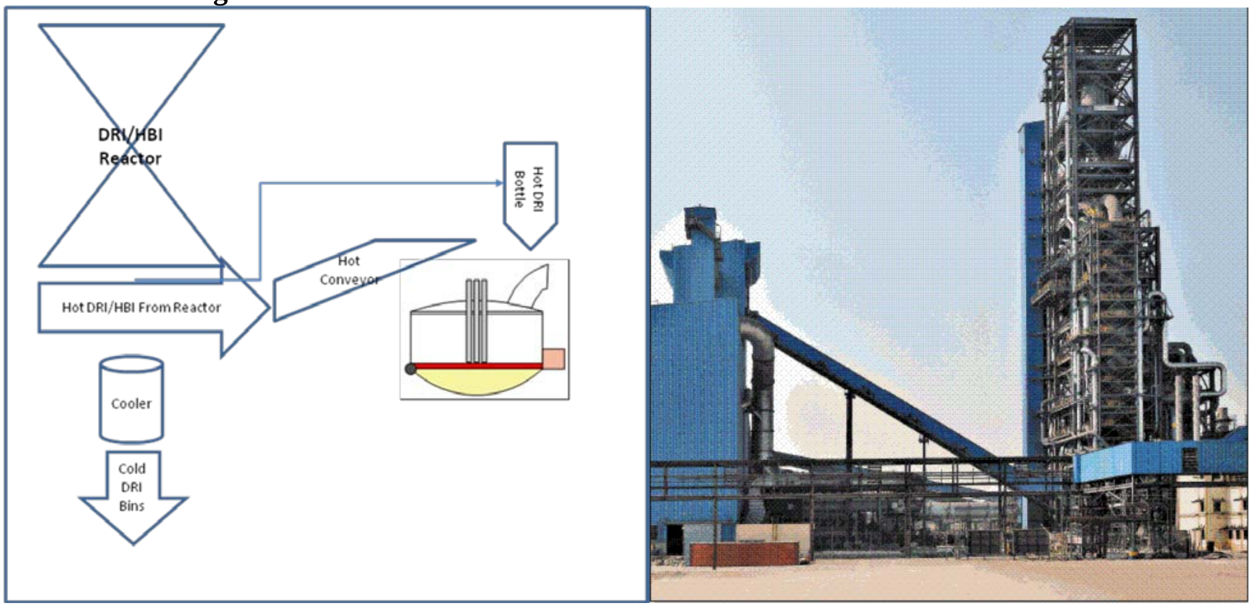

Figure 4.17: Hot Conveyor Transport of Hot DRI/HBI to EAF

Commercial Status: Mature

Contact Information:
OEM'S

Danieli [danielicorp.com]
SMS Siemag [http://www.sms-siemag.de]
HYL (Tenova) [tenovagroup.com
Midrex (Kobe) [midrex.com]

Plants

Ternium Monterrey MX (was HYLSA)
Essar Steel India
Hadeed Saudi Arabia

4.2.7 Control and Automation for EAF Optimization

Description:
With development in recent years of effective probes that can dynamically measure the chemistry of the off gas from the EAF at the exit of the furnace (4th hole in the EAF). Given the data related to the O_2, CO, CO_2, H and N_2 content of the off gas it has been possible to develop computer software systems to dynamically adjust the Oxygen, Carbon, fuel gas addition rates and the electrical power input rate to optimize the overall performance of the melting process.

The basic process involves the installation of sensor probe at the exit point of the off gas from the furnace and the collected data is sent to an analysis unit. Based on the gas analysis from the system the oxygen injection, carbon injection and natural gas rates are adjusted dynamically to maximize the energy yield from all of the potential chemical fuels within the furnace shell. Results in operating furnaces have indicated that total energy inputs (electrical and chemical) to the melting and refining processes can be reduced by up to 0.2 GJ per ton of crude steel.

Net results vary depending on the charge mix used in the furnace. Producers melting 100% scrap charge see the greatest benefit due to the energy recovery from post combustion while there is solid scrap within the furnace shell. Currently there are over 50 installations of this type of technology worldwide.

Energy/Environment/Quality/Cost Benefits:
- Reduced electrical power consumption
- Reduced natural gas consumption
- Reduced carbon injection rate
- Increased productivity

Block Diagram or Photo:

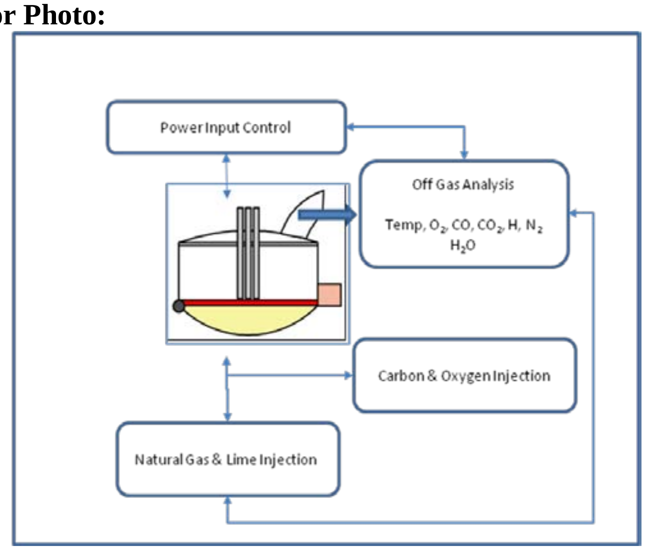

Figure 4.18: EAF Control and Automation Using Off-gas Analyses

Commercial Status: Mature

Contact Information:

OEM'S

Tenova Goodfellow (EFSOP) [www.tenovagroup.com

Plants

Ternium Monterrey MX
Wheeling Pitt USA
Mac Steel USA
TAMSA MX
Ferrier Nord IT

4.2.8 Slag Foaming, Exchangeable Furnace and Injection Technology

Description:

The combination of slag foaming, exchangeable furnace shells and injection technology have, in the last number of years, had a significant impact on the productivity and availability of the Electric Arc Furnace. Slag foaming have made it possible to increase the total energy intensity (both electrical and chemical) within the process while reducing total refractory consumption during melting. In particular, slag foaming has made it possible to increase the total power level of the EAF transformers raising the electrical power intensity from 0.75 MVA per ton of charge to over 1.0 MVA per ton of charge. This in turn has decreased the tap to tap time of the furnace and increased the overall energy efficiency of melting resulting in energy decreases in the range of 2.5% to 3% (0.04 to 0.05 GJ/tonne).

Effective slag foaming is achieved by injecting O_2 into the bath and the slag to generate CO gas as well as add to the chemical energy input to the process. To support the effectiveness of the slag foaming (foaming index) it is also necessary to manage the slag chemistry to achieve the correct slag fluidity and viscosity to hold the CO bubbles in the slag. A properly designed and controlled slag can be foamed up by as much as 4 times the liquid slag volume.

In a good foaming slag operation the tips of the electrodes and the arc are fully submerged in the slag minimizing radiation of the arc energy to the refractory lining and water cooled panels of the furnace shell. The foamed slag also improves the overall efficiency of energy transfer of the heat from the arc to the liquid bath. To optimize these conditions, however, it is necessary to add burnt lime (CaO) and burnt mag-lime (MgO + CaO) at rates that balance the generation of SiO_2 and Al_2O_3 which are delivered to the slag during the melting of the charge material (scrap, DRI, HBI or Pig Iron).

Historically the fluxing materials (CaO, MgO) where added in bulk with the charge which results in a slag chemistry during the first 2/3 of the melt that is not suitable to properly support foaming of the slag. The development of combination injection systems which allow injection of carbon, CaO, MgO and oxygen into the bath at controlled rates during the melt has resolved these issues and made it possible to achieve good slag foaming throughout the melt.

To some extent the development of exchangeable furnaces have enhanced these advantages to the EAF operator. The exchangeable furnace, where the entire furnace and shell can be changed, allow for offline refractory and panel maintenance and increase the available operating hours. In most cases a full furnace exchange can be accomplished in 4 to 6 hours compared to 14 to 24 hours for in-situ maintenance of the furnace shell and refractory.

With the development of the exchangeable furnace the total achievable operating hours has increased from about 82% of calendar hours to as high as 87.5%. In specific instances the combined impact of these technologies have resulted in production increases from 1.25 million tons per annum to 1.5 million tons per annum.

Energy/Environment/Cost/Other Benefits:

- Reduced refractory consumption per ton
- Reduce electrode consumption
- Reduced electrical energy consumption
- Increased productivity
- Improved manpower utilization
- Improved quality of the work environment

Block Diagram or Photo:

- The optimum foaming index changes with the generation of FeO in the slag and the MgO content of the slag needs to be modified to move the slag chemistry into the appropriate range for foaming (blue line)
- The regions outside the optimum foaming zone have poor slag foaming characteristics

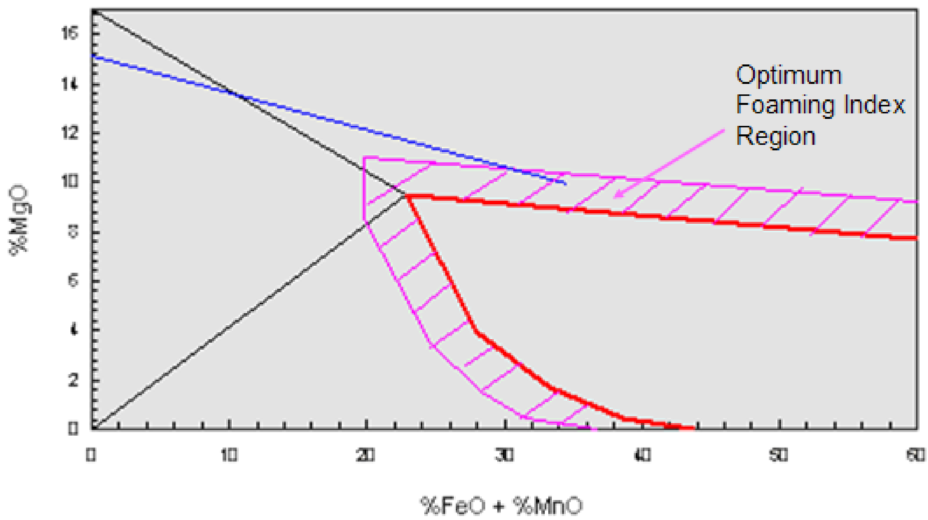

Figure 4.19: Slag Iso-Thermal Diagram

Commercial Status: Mature

Contact Information:
OEM'S

- Danieli [danielicorp.com]
- SMS Siemag [http://www.sms-siemag.de]
- Tenova [tenovagroup.com]
- Siemens VAI [industry.siemens.com]
- LWB Refractories [lwbref.com]

- Hatch [hatch.ca]

Plants

- Nucor [nucor.com]
- Deacero [deacero.com]

4.2.9 Exhaust Gas Treatment Through Gas Cooling, Carbon Injection and Bag filter Dedusting

Description:

EAF primary off-gas (melting, refining) is exhausted through the furnace roof into a water cooled elbow and ductwork. A post-combustion chamber/dust drop-out box is typically provided to ensure complete combustion of carbon monoxide gas and collection of large size dust. The gas is further cooled by either dilution cooling, additional water cooled ductwork, evaporative water sprays or gas-to-air forced draft type heat exchanger, or a combination of these cooling methods. The furnace secondary emissions (charging, tapping, primary fugitives) are captured by a deep storage type meltshop roof mounted canopy hood. The primary and secondary off-gases are mixed in a mixing chamber. A spark-box may be provided to eliminate harmful sparks from the gas stream to protect the filter bags. If required to meet environmental regulations, powdered activated carbon/lignite coke may be injected upstream of the bagfilter for removal of Dioxins/Furans. A bagfilter with appropriately selected bag material is used to remove the particulate matter from the gas stream before it is exhausted to the environment.

Energy/Environment/Cost/Other Benefits:

- Dust emissions of less than 5 mg/Nm3 are achievable with careful selection of filter bag material
- Dioxin/Furan emissions of less than 0.1 ng TEQ/Nm3 are achievable with carbon/coke injection
- Heat extracted from the primary off-gas may be used to heat water or generate steam for use in other parts of the meltshop.

Block Diagram or Photo:

Figure 4.20: EAF Gas Cleaning with Quenching Tower

Commercial Status: Mature
Contact Information:
SMS Siemag AG, Düsseldorf, Germany http://www.sms-siemag.de

4.2.10 ECOARC™

Description:
Cost reduction is an ongoing theme for all mills. Also, the importance of environmental issues such as the elimination of CO_2, dioxide, odors, and other pollutants is increasing. To fulfill these two themes - cost reduction and environmental protection - JSP Steel Plantech Co. had developed the "ECOARC™", a new generation of arc furnace.

Energy/Environment/Cost/Other Benefits:
JSP Steel Plantech Co. has listed the following benefit for the ECOARC:

- Economical/Energy-saving
  - Low power consumption: 200 kWh/ton @40m3N/ton oxygen
  - Low electrode consumption: 0.8-1.0 kg/ton (AC ECOARCTM)
  - Low cost for flexibility of scrap mixing
- Ecological
  - Reduction of CO2
  - Low dioxin emission level, Low dust emission level
  - Quiet operation, Low flicker and harmonics
  - No odor or white smoke
- Off Gas System
  - The off gas from ECOARC™ includes a large volume of combustible ingredients, which minimizes the necessary amount of fuel for post combustion.
  - The off gas volume itself is also minimized by the use of a semi-airtight furnace and off gas ducts.

Block Diagram or Photo:

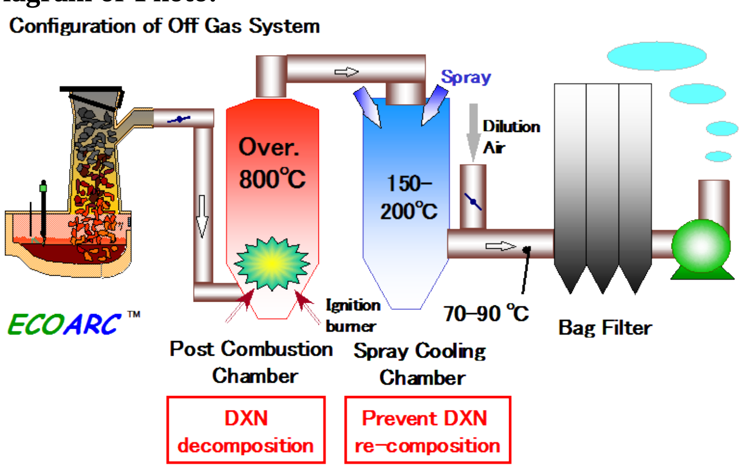

Figure 4.21: Configuration of off gas system in ECOARC ™

Commercial Status: Emerging
Contact Information:
JP Steel Plantech Co.
http://www.steelplantech.co.jp

5 Ladle Refining and Casting

5.1 Ladle Refining for BOF and EAF

No technologies available at the time of publication. Technologies will be added in the future as appropriate.

5.2 Casting

5.2.1 Castrip® Technology

Description
The Castrip® process has been developed to allow the direct casting of thin strip from liquid steel, in gauges currently ranging from 0.8mm to 2.0 mm.

Energy/Environment/Cost/Other Benefits:

- Potential energy savings of 80 to 90% over conventional slap casting and hot rolling methods
- More tolerant of high residual elements without loss of quality, enabling greater flexibility in ferrous feed sourcing
- Higher scrap recycling rates potential and less dependence on pig iron and HBI

Block Diagram or Photo:

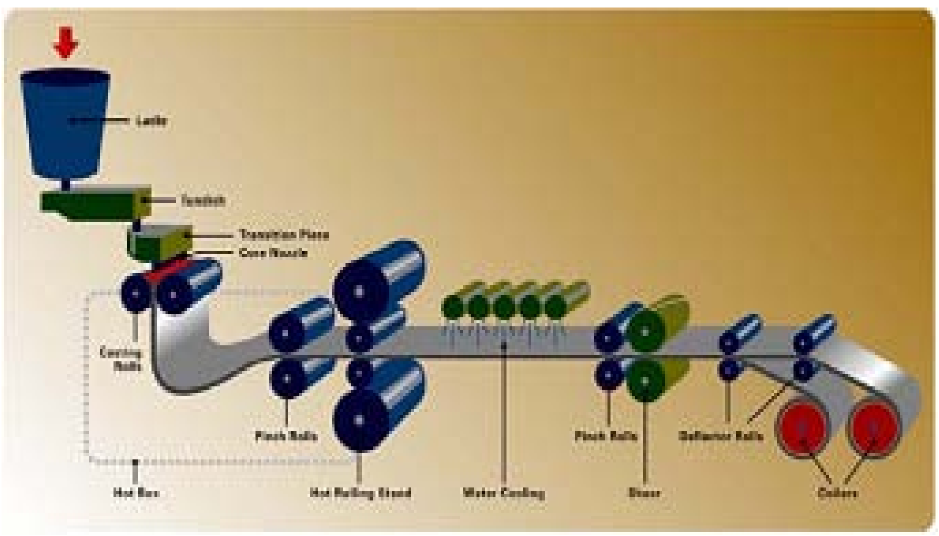

Figure 5.1: Castrip® Process flow diagram

Commercial Status: Emerging

Contact Information:
Castrip LLC
http://www.castrip.com

5.2.2 Thin Slab Casting and Hot Rolling

Description:
Thin-slab casting and hot rolling (TSCHR) is based on a number of processes that are applied together to convert liquid steel into hot rolled coil. The first step is thin slab casting – to cast liquid steel into thin slabs (50 to 90 mm thick) or medium-thick slabs (90-150 mm). In some cases, the caster has provision for in-line reduction of the shell with liquid core or to the solid slab. After casting the temperature of as-cast material is homogenized in a special furnace which is designed to accommodate the long lengths of the cast slabs. Hot rolling can then be performed on the equivalent of finishing stands of a hot strip mill (HSM), or on a leaner mill such as a Steckel mill or a hot planetary mill.

Energy/Environment/Cost/Other Benefits:
Some of the advantages (versus the conventional route for hot strip production) of this include lower fuel consumption, higher liquid steel to hot rolled coil yield, electrical power consumption, lower capital cost, etc. Following benefits have been claimed by technology suppliers:

- Capital cost is ~20% lower for 1-str and ~35% lower for 2-str; TSCR shop length is 30-40% shorter
- Specific energy consumption is lower than that at conventional plants:
  - Versus cold charging of slab (temp 25°C) - lower by ~70 %
  - Versus cold charging of slab (temp 600°C) - lower by ~40%
- Labour and maintenance costs are lower by ~40%
- Easier to produce certain grades – e.g. electrical steels, high silicon steels etc.

Block Diagram or Photo:

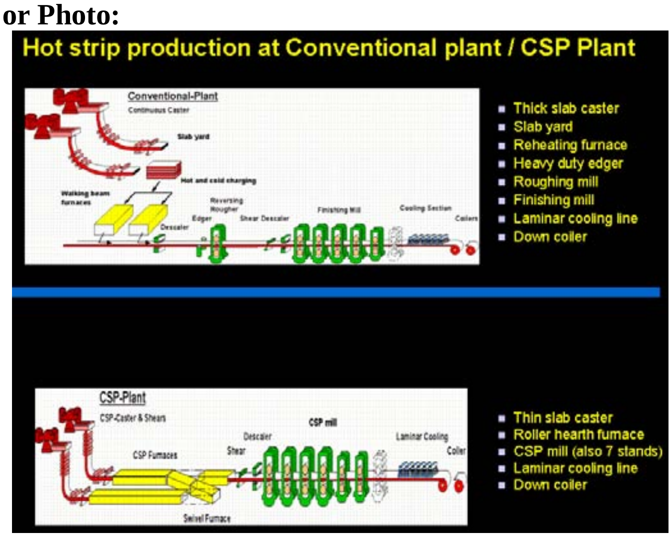

Figure 5.2: CSP process is compared with the conventional process route for hot strip production

Commercial Status: Mature
Contact Information:
CSP (Compact Strip production) by SMS Siemag, FTSR (Flexible thin slab production) by Danieli, QSP (Quality Strip Production, Caster: Sumitomo Heavy Mill: Mitsubishi Hitachi)

5.2.3 Hot Charging to Reheat Furnace of Rolling Mills

Description:
In conventional continuous casting mills with direct hot charging, the cast product enters a reheat furnace for heating to a uniform temperature suitable for downstream rolling and other processing. Some plants follow warm charging – here the slab / billet is charged into the furnace within 24 hours (or 16 hrs or any other limit). In order to carry out this, a number of features are required:

- on-line slab surface inspection[1], hot slab conditioning
- sizing press – caster casts only one width and the width adjustment required for rolling is done by the sizing press
- product mix / caster scheduling

Energy/Environment/Cost/Other Benefits:
- Lower fuel consumption
- Higher liquid steel to hot rolled coil yield

Block Diagram or Photo:

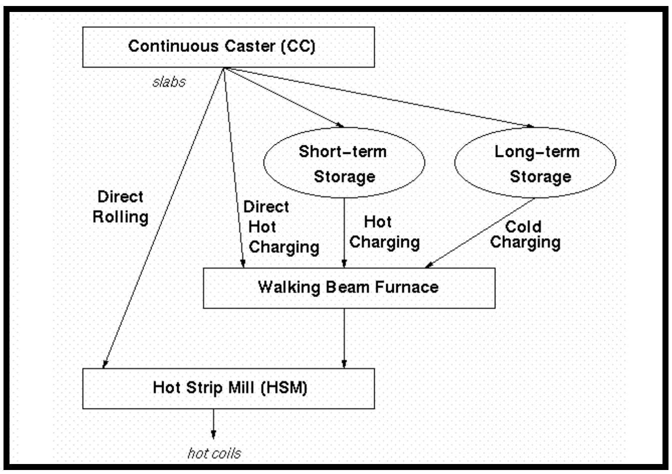

Figure 5.3: Hot Charging to Reheat Furnace of Rolling Mills

Commercial Status: Mature

Contact Information:
SMS Siemag, Simens-VAI, Danieli, Nippon Steel, Kawasaki Steel

References:

[1]Kitagawa et al.: An Automatic Surface Defect Detection System for Hot Ingot Casting Slabs Using an Infrared Scanning Camera and Image Processors, Transactions of the Iron and Steel Institute of Japan Vol.21, No.3(1981) pp.201-210.

6 Rolling and Finishing

No technologies available at the time of publication. Technologies will be added in the future as appropriate.

7 Recycling and Waste Reduction Technologies

7.1 Reducing Fresh Water Use

Description:
To reduce steel works dependence on fresh water, the following efforts have been made at Port Kembla Steelworks, Australia:

- Municipal waste-water reclamation – The treatment of sewerage water using micro-filtration and reverse osmosis technology for re-use as industrial water, up to 20 ML/day
- Internal waste-water recycling schemes – Cooling tower blowdown water from the hot strip mill and slab casters does not go to the drain, but is treated and reused for dust collection in steelmaking
- Stormwater containment initiatives – 13ML synthetic lined water recovery basin in coke ovens area collects rainwater, coal stockpile run-off water, and spent water from coke quenching for re-use at gas processing and coke quenching

Energy/Environment/Cost/Other Benefits:

- Using recycled sewerage water has reduced fresh dam water use on site by 20ML/day
- Hot strip mill and slab caster blowdown water saves steelmaking 0.5ML/day
- Recycling reduces fresh dam water use from 2.3kL/slab tonne to 1.0kL/slab tonne

Block Diagram or Photo:

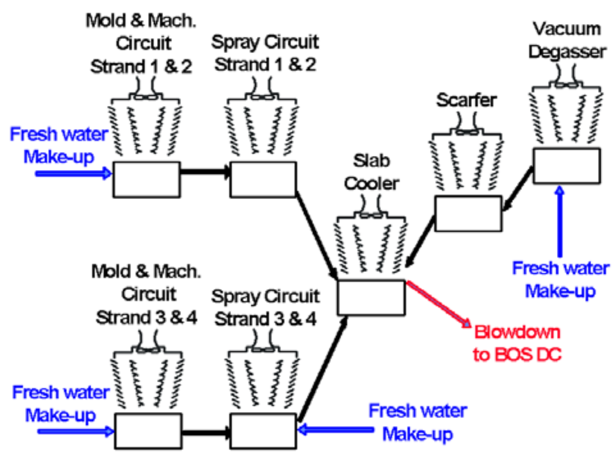

Figure 7.1: Water flow between the slab caster cooling towers

Commercial Status: Mature

Contact information:
Sydney Water
http:///www.sydneywater.com.au

BlueScope Steel
http://www.bluescopesteel.com

7.2 Slag Recycling

Description:
Slag is a by-product of iron and steelmaking, not a waste. Slag pulverization is a process during which water is sprayed when the slag temperature is at 600-800^{o}C. The water spray produces hot steam, which reacts with free calcium oxide and magnesium oxide. Consequently, the slag is pulverized due to the volume expansion, thus making the iron and steel separate naturally from the slag. Slag is also used outside of steel making, e.g., in water/bottom muck purification materials to reduce phosphate concentration in red tides and as marine block to help grow seaweed.

Energy/Environment/Cost/Other Benefits:
- Around 3.8 million t/year of scrap steel is recovered from slag produced
- Revenue generated is equivalent to 3.8 billion Yuan/year, based on 1,000 Yuan ($130 2006 US)/t scrap steel
- Substitute for cement in building industry, thereby reducing energy use in and CO_2 emissions from the cement industry
- Land area occupied by piled slag minimized by slag reutilization
- Application of slag in Japan (marine block and water/bottom much purification materials)
  - Reduce phosphate concentration that causes red tide
  - Fix hydrogen sulfide (cause of blue tide)
  - Grow seaweed to restore lost shallows in seaweed beds
- Other applications include concrete aggregate, railroad ballast, agricultural use, sewage trickling filters, and construction[66]

Block Diagram or Photo:

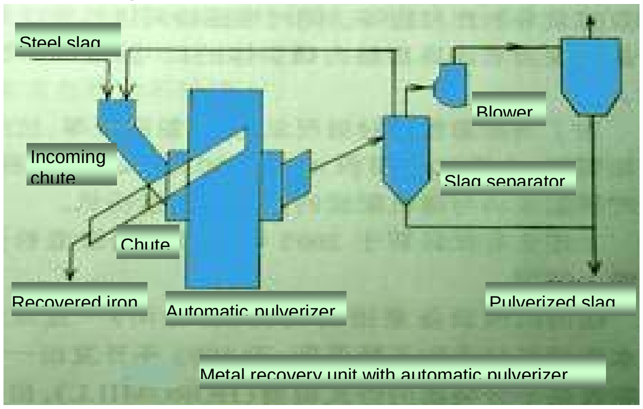

Figure 7.2: Slag pulverization process

Commercial Status: Emerging

Contact information:
Central Engineering Institute of Building Industry, Beitai Steel and Hunan Lianyuan Steel
JFE Steel Corporation
http://www.jfe-steel.co.jp

Japan Iron and Steel Federation
http://www/jisf.or.jp

[66] Baker Environmental, Inc. 1992. *Report on Steel Industry Waster Generation, Disposal Practices, and Potential Environmental Impact.* American Iron and Steel Institute.

7.3 Rotary Hearth Furnace Dust Recycling System

Description:
Dust recycling in the rotary hearth furnace (RHF) was applied at Nippon Steel's Kimitsu Works in 2000. The dust and sludge, along with iron oxide and carbon, are agglomerated into shaped articles and the iron oxide is reduced at high temperatures. Zinc and other impurities in the dust and sludge are expelled and exhausted into off-gas[67].

Energy/Environment/Cost/Other Benefits:
- DRI pellets made from the dust and sludge have 70% metallization and are strong enough to be recycled to the blast furnaces[2]
- Waste reduction and decreased disposal costs
- Extended landfill life
- Recovery of unused resources (recycling iron, nickel, zinc, carbon, etc.)
- Increase in productivity: 1kg of DRI charged per ton of BF smelt pig iron
- Decrease in fuel ratio to BF to 0.2kg/t-pig. Japan Society of Industrial Machinery Manufacturers (JSIM) reports the energy saving of 1400 TJ/year achived by installation of 2 units of this system in Japan[68]
- Decrease in coke ratio by charging DRI to BF

Block Diagram or Photo:

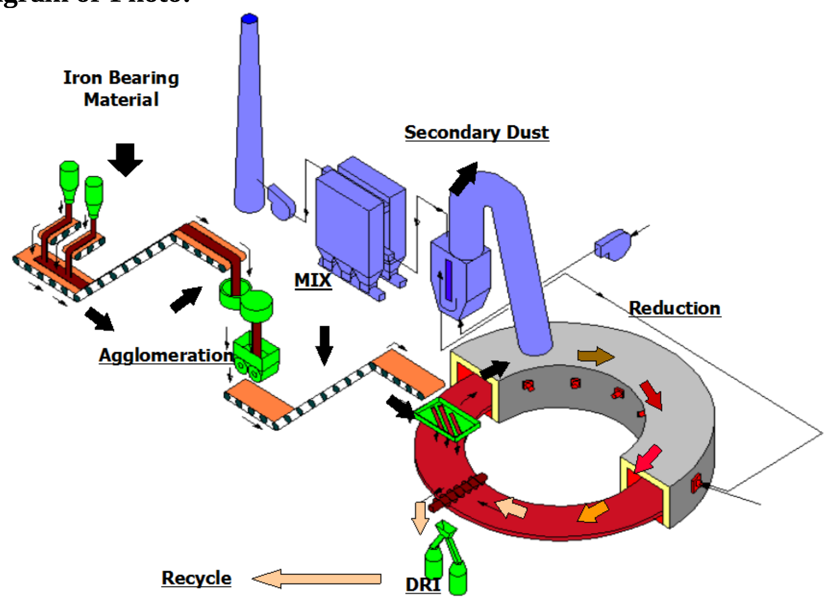

Figure 7.3: General process flow of RHF

Commercial Status: Emerging

Contact information:
Shinjiro Uchida, Nippon Steel Engineering
http://www.nsc-eng.co.jp

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67 Information available at: http://www0.nsc.co.jp/shinnihon_english/kenkyusho/contenthtml/n94/n9424.pdf
68 Japan Society of Industrial Machinery Manufacturers. Available at: http://www.jsim.or.jp/english/01.html

7.4 Activated Carbon Absorption

Description:
Use of activated carbon to remove high pollutant concentrations has been proven successful in many cases. In cokemaking, activated carbon absorption system is used not only to eliminate the yellow brown color typical of coke wastewater (which may cause complaints from stakeholders) but also to reduce the COD of the secondary wastewater treatment plant.

Energy/Environment/Cost/Other Benefits:
- Eliminate the yellow brown color of coke wastewater
- Significant reduction of COD of the secondary wastewater treatment plant to below 5 mg/ℓ
- Heavy metals removal

Block Diagram or Photo:

Figure 7.4: Activated Carbon Equipment

Commercial Status: Mature

Contact information:
Mr. Youngdo Jang
Department of Environment & Energy, POSCO
T +82-54-220-5773
ydjang@posco.co.kr

Installation information:
First commercial facility in Kwangyang; secondary wastewater treatment plant operated since 1988 and installation of coke wastewater plant was done in 2002.

8 Common Systems

8.1 Auditing Rotary Machines for Pump Efficiency

Description:
ESCO-PRO (POSCO venture company) developed auditing methodology for pump efficiency to measure temperature and pressure of fluid. From the inlet and outlet temperature and pressure measurement, the pump efficiency is calculated.

Energy/Environment/Cost/Other Benefits:

- Energy saving between 20-30% of electricity use in pumping system depending on how pumps are operated.
- \$63,000-\$65,000/year reduction in power consumption

Block Diagram or Photo:

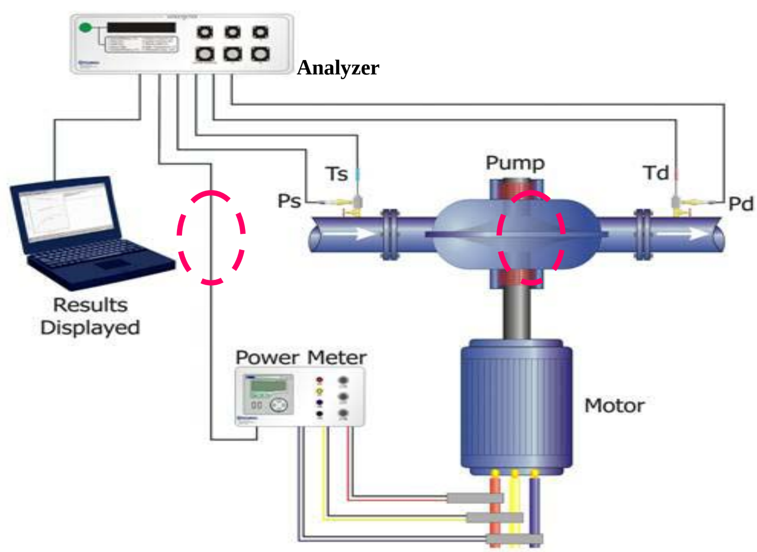


Figure 8.1: Flow diagram of auditing rotary machines system

Commercial Status: Mature

Contact information:
Yun Sik Jung, Environmental & Energy Dept., POSCO
http://www.posco.co.kr

8.2 AIRMaster+ Software Tool – Improved Compressed Air System Performance

Description:
The AIRMaster+ software tool models the supply-side of a compressed air system to identify efficiency improvement opportunities. Using plant-specific data, the free software tool evaluates the operational costs for various compressed air equipment configurations and system profiles. The software provides estimates of potential savings gained from selected energy efficiency measures and calculates the associated simple payback periods.

The AIRMaster+ software includes a database of industry-standard compressors and creates an inventory specific to the actual air compressors onsite based on user input. The software simulates existing and modified compressed air system operations. It can model part-load system functions for an unlimited number of rotary screws, reciprocating and centrifugal air compressors operating simultaneously with independent control strategies and schedules.

Energy/Environment/Cost/Other Benefits:
- Develops a 24-hour metered airflow or power data load profile for each compressor
- Calculates life-cycle costs
- Inputs seasonal electrical energy and demand charges
- Tracks maintenance histories for systems and components
- Evaluates energy savings potentials of the following energy efficiency actions: reducing air leaks, improving end-use efficiency, reducing system air pressure, using unloading controls, adjusting cascading set points, using an automatic sequencer, reducing run-time, and adding a primary receiver volume

2006, 2007 and 2008 Annual Saving Opportunities						
	Identified Annual Savings			Implemented Annual Savings		
System Area	number of completed energy assessments	Identified Source Energy Savings Upgrades (TBtu)	Identified Cost Savings ($)	Implemented Source Energy Savings (TBtu)	Implemented Cost Savings ($)	Implemented CO2 Savings (metric tons)
Compressed Air	139	3.19	19,264,505	0.94	5,095,041	55,069

Block Diagram or Photo:

Figure 8.2: Screen Shot of AIRMaster+

Commercial Status: Mature

Contact information:
US DOE Industrial Technologies Program
http://www1.eere.energy.gov/industry/bestpractices/software.html

8.3 Combined Heat and Power Tool – Improved Overall Plant Efficiency and Fuel Use

Description:
The Combined Heat and Power (CHP) tool identifies opportunities for the application of CHP systems to re-use waster heat and determines optimal equipment size, implementation costs, and the payback for investing in CHP technologies.

The tool can be used to size or select design parameters for a new CHP system or to optimize a system in use. Site-specific data can be entered into the tool or default settings from the tool's database can be used to generate:

- Current energy use and performance data for selected furnaces/boilers and turbines
- Energy use data for a CHP system
- Estimated energy savings
- Cost details for implementing a CHP system
- Payback period based on cost data provided for the fuel, electricity, and equipment used in a CHP system

Energy/Environment/Cost/Other Benefits:

- Evaluates the feasibility of using gas turbines to generate power and using turbine exhaust gases to supply heat to industrial heating systems
- Provides analysis for the following three commonly used systems:
  - Fluid Heating in Fired Heat Exchangers
  - Exhaust Gas Heat Recover in Heaters
  - Duct Burner Systems

Block Diagram or Photo:

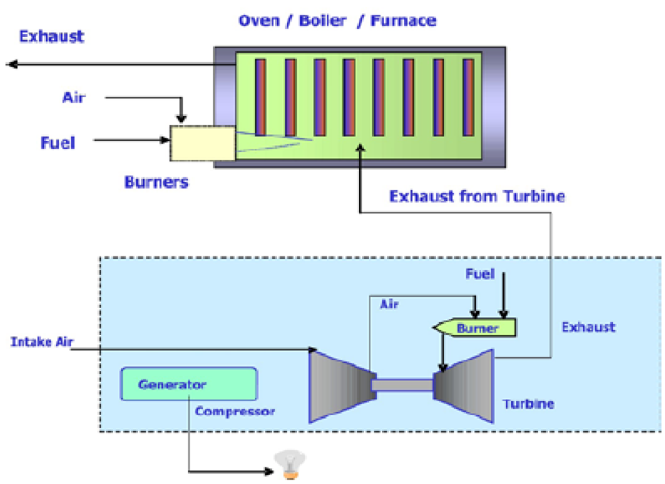


Figure 8.3: Example of CHP application – exhaust gases from a turbine is used to heat fluids in a heat exchanger

Commercial Status: Mature

Contact information:
US DOE Industrial Technologies Program
http://www1.eere.energy.gov/industry/bestpractices/software.html

8.4 Fan System Assessment Tool – Efficiency Enhancement for Industrial Fan Systems

Description:
The Fan System Assessment Tool (FSAT) quantifies energy consumption and energy savings opportunities in industrial fan systems, helping users understand how well their fan systems are operating and determine the economic benefit of system modifications.

FSAT allows users to input information about their fans and motors and calculates the energy used by the fan system and the overall system efficiency. It approximates potential energy and cost savings, and helps determine which options are most economically viable when multiple opportunities exist.

Energy/Environment/Cost/Other Benefits:

- Capabilities include:
  - Determining fan system efficiency
  - Identifying degraded fans
  - Collecting data for trending system operation
  - Quantifying potential costs and energy savings for various operating configurations
- Help users calculate the differences between rated and installed performance due to issues such as:
  - High duct velocity
  - Discharge dampers locked in position
  - Obstructed inlets
  - Incorrectly sized fans
  - Poor duct geometry
  - Degraded impellers

2006, 2007 and 2008 Annual Saving Opportunities						
	Identified Annual Savings			Implemented Annual Savings		
System Area	number of completed energy assessments	Identified Source Energy Savings Upgrades (TBtu)	Identified Cost Savings ($)	Implemented Source Energy Savings (TBtu)	Implemented Cost Savings ($)	Implemented CO2 Savings (metric tons)
Fans	36	6.83	39,681,130	0.05	346,200	3,022

Block Diagram or Photo:

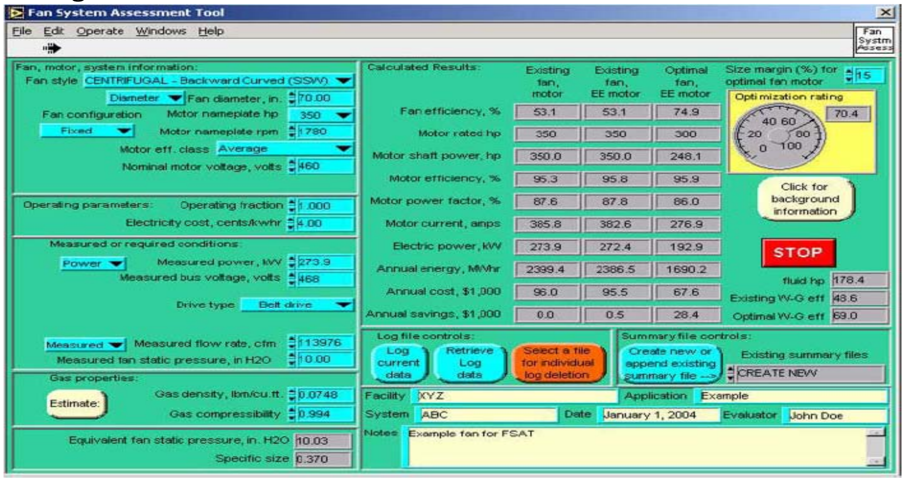


Figure 8.4: FSAT main data input screen

Commercial Status: Mature

Contact information:
US DOE Industrial Technologies Program
http://www1.eere.energy.gov/industry/bestpractices/software.html

8.5 MotorMaster+ International – Cost-Effective Motor System Efficiency Improvement

Description:
MotorMaster+ International helps plants manage their motor inventory and make cost-effective decisions when repairing and replacing motor systems.

Based on site-specific user input and database information for typical motor functionality, the tool determines energy and cost savings for motor selection decisions by taking into account variables, such as motor efficiency at its load point, purchase price, energy costs, operating hours, load factor, and utility rebates.

Energy/Environment/Cost/Other Benefits:
- Analysis features allows for the selection of the best available motor for a given application, with the determination of demand reductions, greenhouse gas emission reductions, simple payback, cash flows, and after-tax rate of return on investment
- Allows to conduct economic analyses using various currencies and to insert applicable country or regional motor full-load minimum efficiency standards, and country-specific motor repair and installation cost defaults
- Software comprehensive database contains:
  - Available data for 60 Hz National Electrical Manufacturers Association (NEMA) and 50 Hz metric or International Electrotechnical Commission (IEC) motors
  - Over 25,000 NEMA motors and over 7,200 IEC motors
  - Ability to modify motor operating details in the database

Block Diagram or Photo:

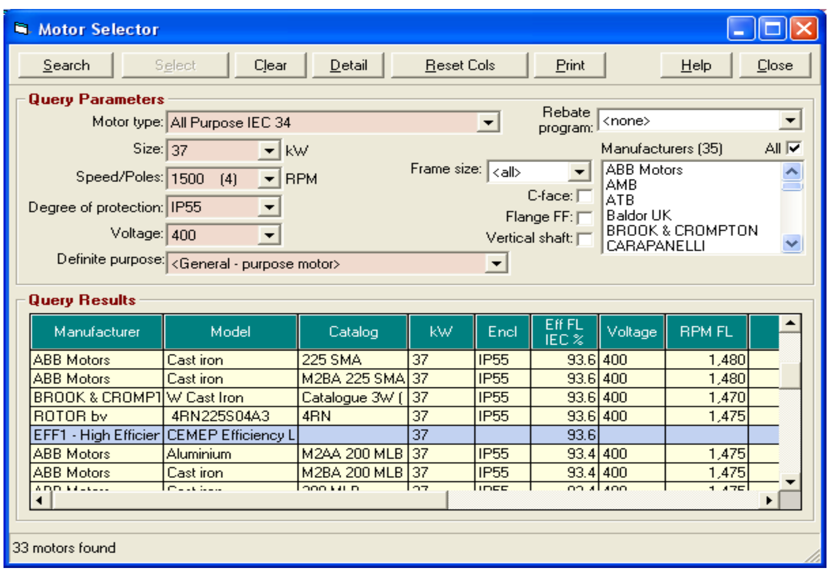


Figure 8.5: Screen shot of MotorMaster+ International interface

Commercial Status: Mature

Contact information:
US DOE Industrial Technologies Program
http://www1.eere.energy.gov/industry/bestpractices/software.html

8.6 NOx and Energy Assessment Tool – Reduced NOx Emissions and Improved Energy Efficiency

Description:
The NOx and Energy Assessment Tool (N_xEAT) provides a systematic approach to estimate NOx emissions and analyze NOx and energy reductions methods and technologies.

N_xEAT allows plants to analyze the effects of NOx reductions methods and energy efficiency practices by providing equipment inventory and configuration information. The tool targets specific systems, such as fired heaters, boilers, gas turbines, and reciprocating engines to help identify the NOx and energy savings potentials associated with each option. The tool also provides calculators that aid in comparisons between options.

Energy/Environment/Cost/Other Benefits:
Based on inputted plant-specific information and the N_xEAT database, the tool creates a report presenting:

- Profile of plant's current NOx emissions, energy use, and annual energy cost for NOx-generating equipment
- Energy savings analysis
- Calculation and comparisons of NOx emissions and capital reduction for each analysis
- Table of charts of NOx and energy savings

Block Diagram or Photo:

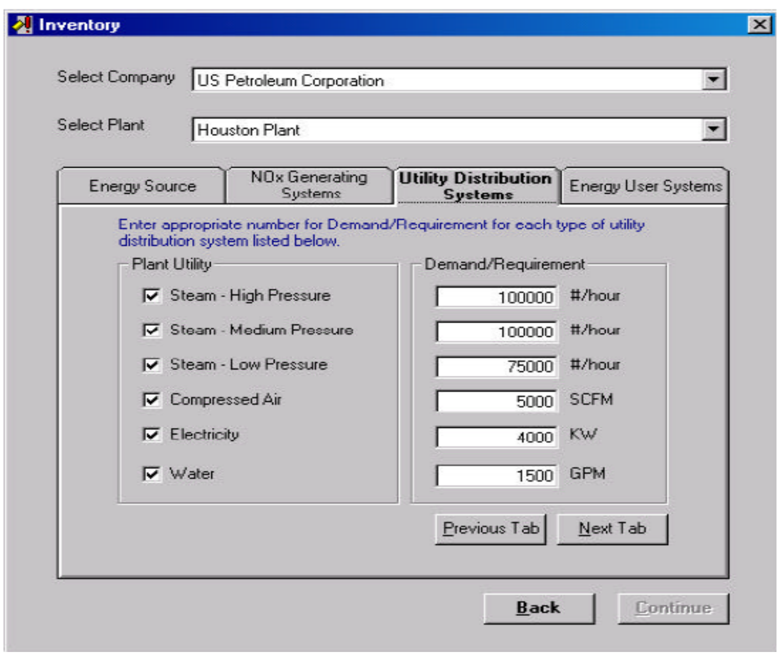


Figure 8.6: N_xEAT screen shot

Commercial Status: Mature

Contact information:
US DOE Industrial Technologies Program
http://www1.eere.energy.gov/industry/bestpractices/software.html

8.7 Process Heating Assessment and Survey Tool – Identify Heat Efficiency Improvement Opportunities

Description:

The Process Heating Assessment and Survey Tool (PHAST) identifies ways to increase energy efficiency by surveying all process heating equipment within a facility, determining the equipment that use the most energy, and evaluating energy use under various operating scenarios.

Based on user input guided by the tool and a database of thermal properties, PHAST calculates energy use in specific pieces of equipment and throughout the process heating system. The output facilitates the identification and prioritization of efficiency improvements by suggesting methods to save energy in each area where energy is used or wasted, and by offering a listing of additional resources.

Energy/Environment/Cost/Other Benefits:

Capabilities of tool include:

- Calculation of potential savings
- Comprehensive equipment survey
- Determination of wasted energy
- Identified significant potential savings in a steel reheating furnace indicating that:
  - Fuel use could be reduced by approximately 30MM Btu/hour for the heating zone and 5MM Btu/hour for the soak zone
  - 2MM Btu/hour could be saved by reducing losses through openings
  - Total potential savings for the unit of 37MM Btu/hour, or 22% of all energy used by the furnace
  - Suggested low-cost improvements included better control of the air-fuel ratio and installation of radiation shields (curtains that eliminate radiation heat loss)

2006, 2007 and 2008 Annual Saving Opportunities						
System Area	**Identified Annual Savings**			**Implemented Annual Savings**		
	number of completed energy assessments	Identified Source Energy Savings Upgrades (TBtu)	Identified Cost Savings ($)	Implemented Source Energy Savings (TBtu)	Implemented Cost Savings ($)	Implemented CO2 Savings (metric tons)
Process Heating	225	43.64	319,218,778	5.09	38,957,875	273,638

Block Diagram or Photo:

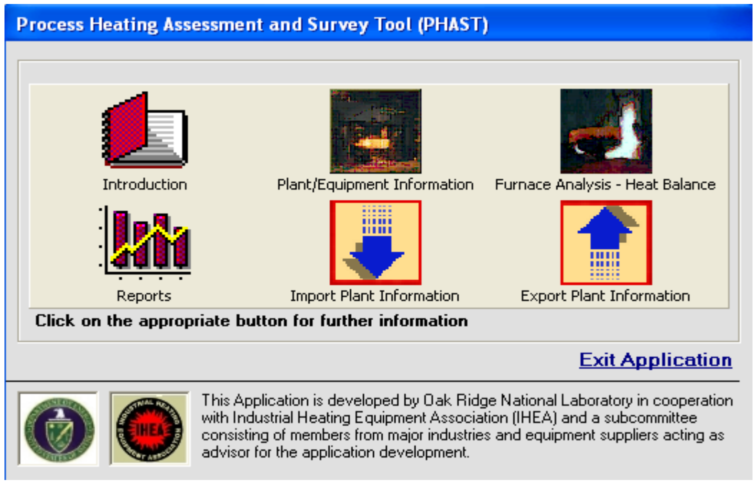


Figure 8.7: Screen shot of PHAST

Commercial Status: Mature

Contact information:
US DOE Industrial Technologies Program
http://www1.eere.energy.gov/industry/bestpractices/software.html

8.8 Quick Plant Energy Profiler – First Step to Identify Opportunities for Energy Savings

Description:
Quick Plant Energy Profiler (Quick PEP), a free online software tool, helps facilities quickly diagnose their energy use and begin identifying opportunities for savings. Quick PEP uses basic information about major energy-consuming systems to create a report that profiles plant energy usage. The tool's output presents the energy usage for plant processes and identifies specific targeted ways to economically save energy and help reduce environmental emissions associated with energy production and use.

Energy/Environment/Cost/Other Benefits:
Capabilities of tool include:
- Details plant energy consumption
- An overview of energy generation, purchases, and associated costs
- Potential energy and cost savings
- Customized list of suggested 'next steps' to begin implementing energy-saving measures

Block Diagram or Photo:

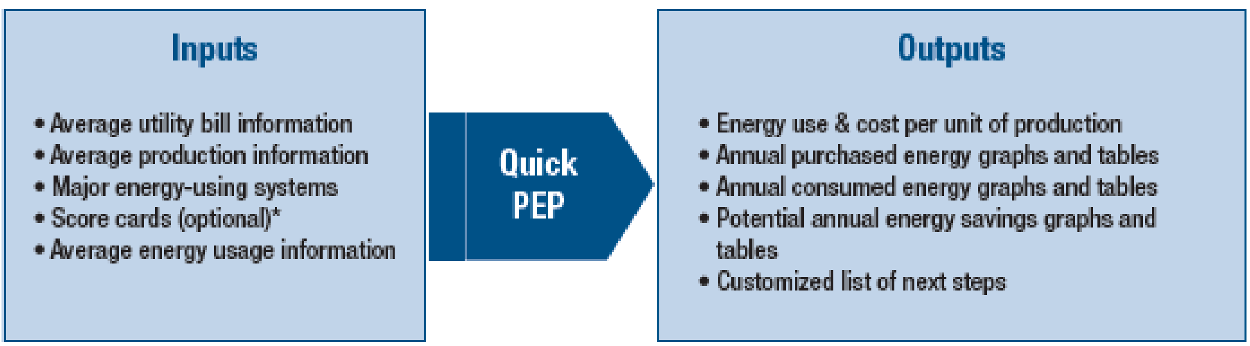


Figure 8.8: Quick PEP process flow diagram

Commercial Status: Mature

Contact information:
US DOE Industrial Technologies Program
http://www1.eere.energy.gov/industry/bestpractices/software.html

8.9 Steam System Tools – Tools to Boost Steam System Efficiency

Description:
The following suite of software tools help enable facilities to evaluate steam systems and to identify opportunities for improvement.

Steam System Scoping Tool
This tool quickly evaluates the plant's entire steam system and spots areas that are the best opportunities for improvement, suggesting various methods to save steam energy and boost productivity. It profiles and grades steam system operations and management from user-inputted steam system operating practices, boiler plant operating practices, and distribution and recovery practices, and then compares user's steam system operations against identified best practices.

Steam System Assessment Tool
The Steam System Assessment Tool (SSAT) develops approximate models of real steam systems to quantify the magnitude (energy, cost, and emission savings) of key potential steam improvement opportunities. SSAT contains all the key features of typical steam systems – boilers, backpressure turbines, condensing turbines, deaerators, letdowns, flash vessels, and feed water heat exchangers.

The tool analyzes boiler efficiency, boiler blowdown, cogeneration, steam cost, condensate recovery, heat recovery, vent steam, insulation efficiency, alternative fuels, backpressure turbines, steam traps, steam quality, and steam leaks. Its features include a steam demand savings project, a user-defined fuel model, a boiler stack loss worksheet for fuels, and a boiler flash steam recovery model.

3E Plus
3E Plus calculates the most economical and energy efficient industrial insulation thickness for user-inputted operating conditions in order to conserve energy and avoid over-insulation expenses.
Users can utilize built-in thermal performance relationships of generic insulation materials or supply conductivity data for other materials.

Energy/Environment/Cost/Other Benefits:
Steam system tools allow the user to evaluate what-if scenarios for the following key improvement opportunities:

- Boiler efficiency/blowdowns
- Utilizing back pressure turbines to let down steam
- Steam trap operating efficiencies
- Vent steam
- Cogeneration Opportunities
- Condensation recovery
- Alternate Fuels
- True cost of steam
- Heat recovery
- Steam leaks
- Steam quality
- Insulation efficiencies

2006, 2007 and 2008 Annual Saving Opportunities						
System Area	**Identified Annual Savings**			**Implemented Annual Savings**		
	number of completed energy assessments	Identified Source Energy Savings Upgrades (TBtu)	Identified Cost Savings ($)	Implemented Source Energy Savings (TBtu)	Implemented Cost Savings ($)	Implemented CO2 Savings (metric tons)
Steam	306	73.06	599,289,663	19.08	101,131,495	1,472,115

Block Diagram or Photo:

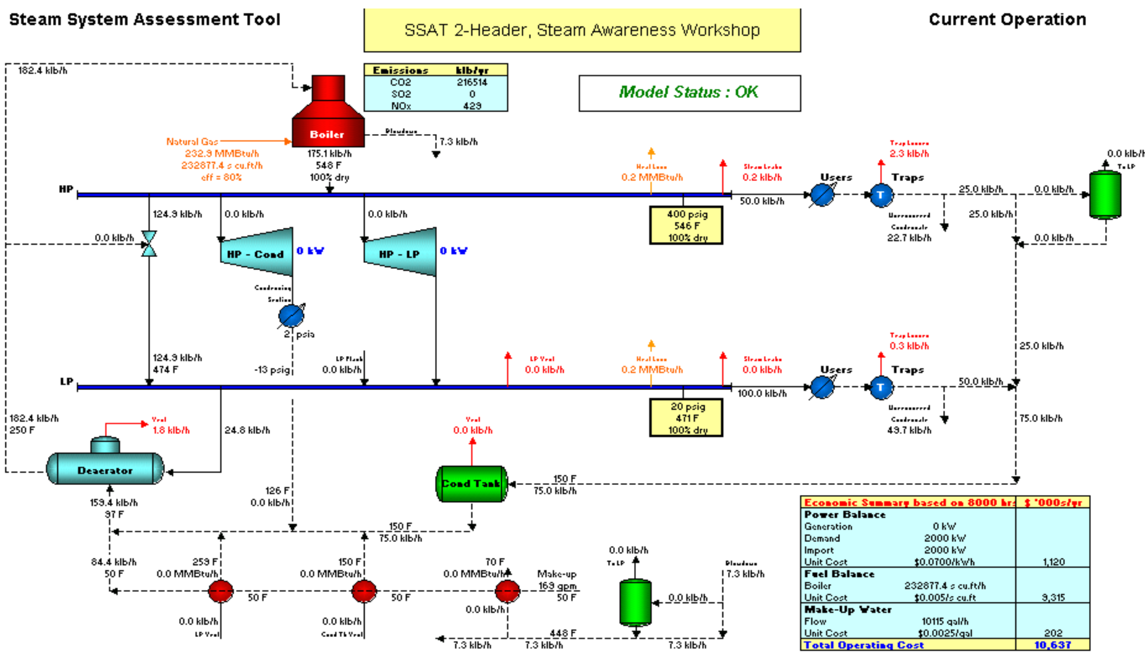
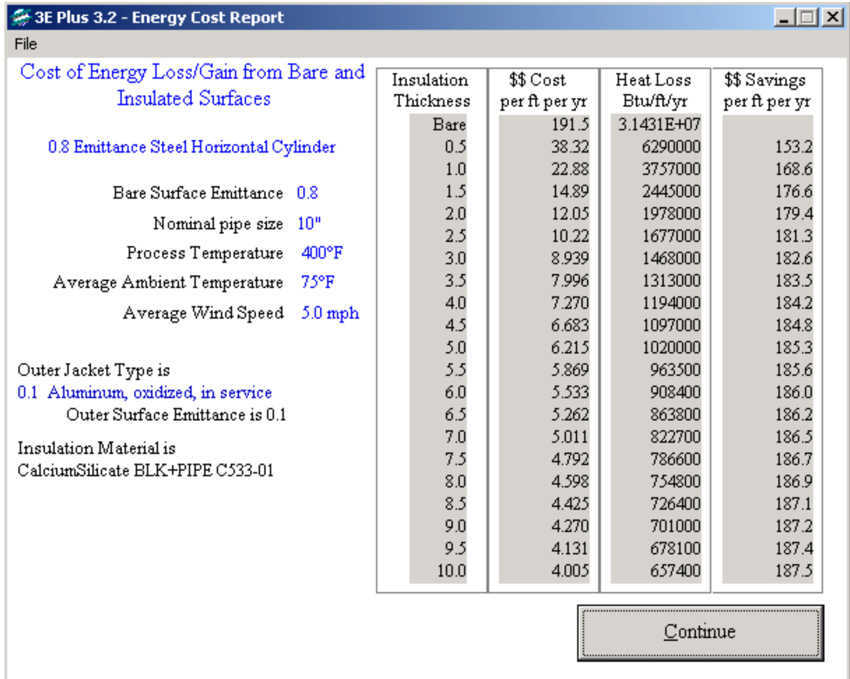


Figure 8.9: Model diagram of Steam System Assessment Tool


3E Plus 3.2 - Energy Cost Report
File

Cost of Energy Loss/Gain from Bare and Insulated Surfaces

0.8 Emittance Steel Horizontal Cylinder

Bare Surface Emittance 0.8
Nominal pipe size 10"
Process Temperature 400°F
Average Ambient Temperature 75°F
Average Wind Speed 5.0 mph

Outer Jacket Type is
0.1 Aluminum, oxidized, in service
Outer Surface Emittance is 0.1

Insulation Material is
CalciumSilicate BLK+PIPE C533-01

Insulation Thickness	$$ Cost per ft per yr	Heat Loss Btu/ft/yr	$$ Savings per ft per yr
Bare	191.5	3.1431E+07	
0.5	38.32	6290000	153.2
1.0	22.88	3757000	168.6
1.5	14.89	2445000	176.6
2.0	12.05	1978000	179.4
2.5	10.22	1677000	181.3
3.0	8.939	1468000	182.6
3.5	7.996	1313000	183.5
4.0	7.270	1194000	184.2
4.5	6.683	1097000	184.8
5.0	6.215	1020000	185.3
5.5	5.869	963500	185.6
6.0	5.533	908400	186.0
6.5	5.262	863800	186.2
7.0	5.011	822700	186.5
7.5	4.792	786600	186.7
8.0	4.598	754800	186.9
8.5	4.425	726400	187.1
9.0	4.270	701000	187.2
9.5	4.131	678100	187.4
10.0	4.005	657400	187.5

Continue

Figure 8.10: Screen shot of 3E Plus

Commercial Status: Mature

Contact information:
US DOE Industrial Technologies Program
http://www1.eere.energy.gov/industry/bestpractices/software.html

8.10 Variable Speed Drives for Flue Gas Control, Pumps and Fans

Description:
Variable speed drives (VSDs) better match speed to load requirements for motor operations. VSD systems are offered by many suppliers and are available worldwide.

Energy/Environment/Cost/Other Benefits:

- Based on experience in the UK:
  - Electricity savings of 42% are possible through the use of VSDs on pumps and fans year[69]
  - Payback of 3.4 years, assuming an electricity price of 3pence/kWh, under U.S. 1994 conditions[70]
  - Costs of $1.3/t product

Block Diagram or Photo:

Figure 8.11: VSD on 300-hp boiler draft fan

Commercial Status: Mature

Contact information:
None avalable.

[69] Anonymous, 1994. "Energy Saving VSD Quench Pumps," Steel Times, April: 150.
[70] International Energy Agency, 1995. *Energy Prices and Taxes, First Quarter 1995*, Paris: IEA.

8.11 Regenerative Burner

Description:
A regenerative burner is a heat recovery system that recovers the waste heat of the furnace exhaust gas to heat-up the combustion air of the furnace. The regenerative burner uses heat reservoirs and dual heat-recovering generators at each burner to channel heat more efficiently. During combustion, one side of a burner combusts fuel while the other accumulates the exhaust heat into the heat-recovering generator. Then the burners switch so that the one accumulating heat combusts the fuel and the other now accumulates exhaust heat.

Energy/Environment/Cost/Other Benefits:
- 20-50% of energy reduction possible, depending on types of furnace and condition of fuel. NEDO reports the energy saving of 1900-2390 GJ/year for the system with 110 tonne/h billets heating[71]
- Up to 50% NOx reduction possible with high temperature combustion
- Excellent operational reliability, with introduction of regenerative burner systems in over 540 furnaces in various Japanese industries

Block Diagram or Photo:

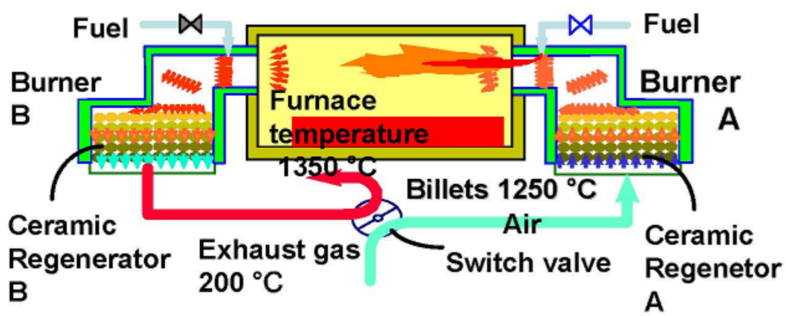


Figure 8.12: Application of regenerative burner

Commercial Status: Mature

Contact information:
JFE Steel Corporation
http://www.jfe-steel.co.jp/
Japan Iron and Steel Feferation (JISF)
http://www.jisf.or.jp

[71] NEDO (New Energy and Industrial Technology Development Organization, Japan), 2008. *Global Warming Countermeasures: Japanese Technologies for Energy Savings/GHG Emissions Reduction (2008 Revised Edition)*. Available at: http://www.nedo.go.jp/library/globalwarming/ondan-e.pdf

9 General Energy Savings & Environmental Measures

9.1 Energy Monitoring and Management Systems

Description:

This measure includes site energy management systems for optimal energy recovery and distribution between various processes and plants. A wide variety of such energy management systems exist[72,73].

Energy/Environment/Cost/Other Benefits:

- Tata Iron and Steel Company (formerly Hoogovens, The Netherlands and British Steel, Port Talbot, UK):
  - Energy savings estimated to be 0.5% or fuel savings of 0.12 GJ/t of product and electricity savings of 0.01 GJ_e/t of product[74,75]
  - Costs estimated to be approximately $0.15/t crude steel based on $0.8M for the system in the Netherlands[74]

Block Diagram or Photo:

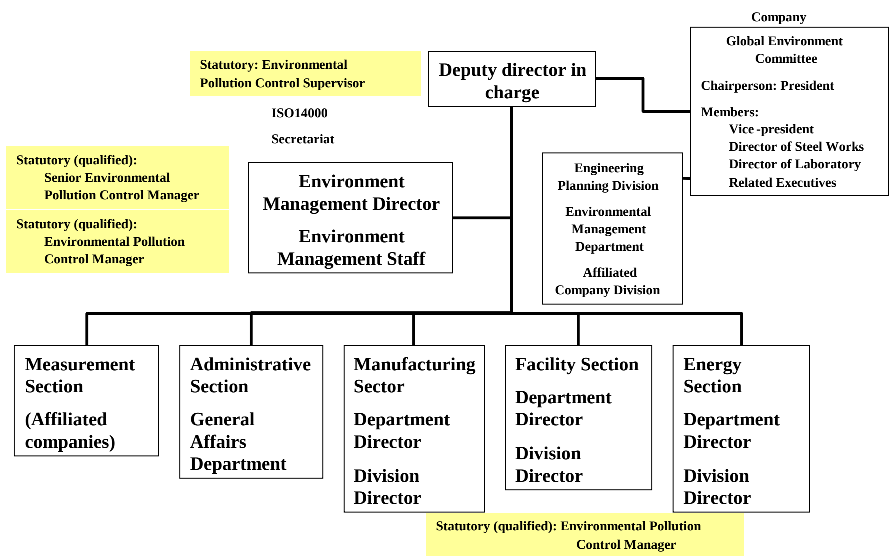


Figure 9.1: Environmental management system at steel works organizational chart

Commercial Status: Mature

Contact Information: Not available

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[72] Worrell, E. and C. Moore, 1997. "Energy Efficiency and Advanced Technologies in the Iron and Steel Industry," in: Proceedings 1997 ACEEE Summer Study on Energy Efficiency in Industry, Washington, DC: ACEEE.
[73] Caffal, C., 1995. "Energy Management in Industry," CADDET Analyses Series 17, Sittard, The Netherlands: Caddet.
[74] Farla, J.C.M., E. Worrell, L. Hein, and K. Blok, 1998. Actual Implementation of Energy Conservation Measures in the Manufacturing Industry 1980-1994, The Netherlands: Dept. of Science, Technology & Society, Utrecht University.
[75] ETSU, 1992. "Reduction of Costs Using an Advanced Energy Management System," Best Practice Programme, R&D Profile 33, Harwell, UK: ETSU

9.2 Cogeneration

Description:
All plants and sites that need electricity and heat (i.e. steam) in the steel industry are excellent candidates for cogeneration. Conventional cogeneration uses a steam boiler and steam turbine (back pressure turbine) to generate electricity. Steam systems generally have a low efficiency and high investment costs. Current steam turbine systems use the low-cost waste fuels, which may have been vented before, e.g., Arcelor Mittal and US Steel Gary Works in the United States[76]. Modern cogeneration units are gas turbine based, using a simple cycle system (gas turbine with waste heat recovery boiler), a Cheng cycle or STIG (with steam injection in the gas turbine), or a combined cycle integrating a gas turbine with a steam cycle for larger systems. The latter system can also be used to're-power' existing steam turbine systems. Gas turbine systems mainly use natural gas. Integrated steel plants produce significant levels of off-gases (coke oven gas, blast furnace gas and basic oxygen furnace-gas). Specially adapted turbines can burn these low calorific value gases at electrical generation efficiencies of 45% (low heating value), but internal compressor loads reduce these efficiencies to 33%[77]. Mitsubishi Heavy Industries has developed such a turbine and it is now used in several steel plants, e.g., Kawasaki Chiba Works (Japan)[78] and Tata Iron and Steel Company (formerly Hoogovens, The Netherlands)[79]. Given the low level of steam demand in secondary steel making plants, most of the cogeneration would apply to integrated facilities.

Energy/Environment/Cost/Other Benefits:
- Increased electricity generation of 1.1 GJ/t crude steel (primary energy)
- Investments for turbine systems are $1090/kWe[79]. Total investment costs estimated to be $14.5/t crude steel.
- Low NOx emissions of 20 ppm[77].

Block Diagram or Photo:

Figure 9.2: Gas turbine systems

Commercial Status: Mature

Contact Information: Not available

[76] Hanes, C., 1999. USS/Kobe Steel, Personal communication, June 1999.
[77] Mitsubishi Heavy Industries, 1993. High Efficiency From Low BTU Gas, Outline of 145 MW Combined Cycle Power Plant for Kawasaki Steel Corporation, Chiba Works, Mitsubishi Heavy Industries, Ltd., Tokyo, Japan.
[78] Takano, H., Kitauchi, Y., and Hiura, H., 1989. Design for the 145 MW Blast Furnace Gas Firing Gas Turbine Combined Cycle Plant," Journal of Engineering for Gas Turbines and Power, 111 (April): 218-224.
[79] Anonymous, 1997c. "Warmtekrachteenheid van 144 MWe bij Hoogovens" Energie en Milieuspectrum, October 1997, p.9.

9.3 Technology for Effective Use of Slag

Description:
Slag can be employed for various end uses outside of steel making:
- Converting slag as a purification catalyst can help restore ecosystems in water areas.
- In concrete and as a low-quality aggregate
- For land improvement

Energy/Environment/Cost/Other Benefits:
- Slag usage in marine applications is a new field with huge potential for shoreline improvement and restoration of lost shallows and seaweed beds
- Using BF slag in cement manufacturing helps to reduce energy use and CO_2 emission by eliminating granulation and heating [340 kg-CO_2/t slag]

Block Diagram or Photo:
None available

Commercial Status: Emerging or commercial:
Converting slag for marine usage is emerging
Use of slag in the cement industry is commercial.

Contact Information:
Japan Iron and Steel Federation

9.4 Hydrogen Production

Description:
Coke oven gas (COG), a byproduct gas of the iron-making process, contains around 55% hydrogen. It is easy to produce hydrogen with high purity from COG by a very simple process called pressure swing adsorption (PSA). Significant efforts to recover sensible heat of COG as hydrogen enrichment are under way. Developing proper catalysts is the key to success.

Energy/Environment/Cost/Other Benefits:
- Hydrogen is expected to be an important energy carrier for fuel cells
- Because of its ease of production, its abundance, and its distribution, COG is one of the major candidates for a hydrogen source in the future

Block Diagram or Photo:

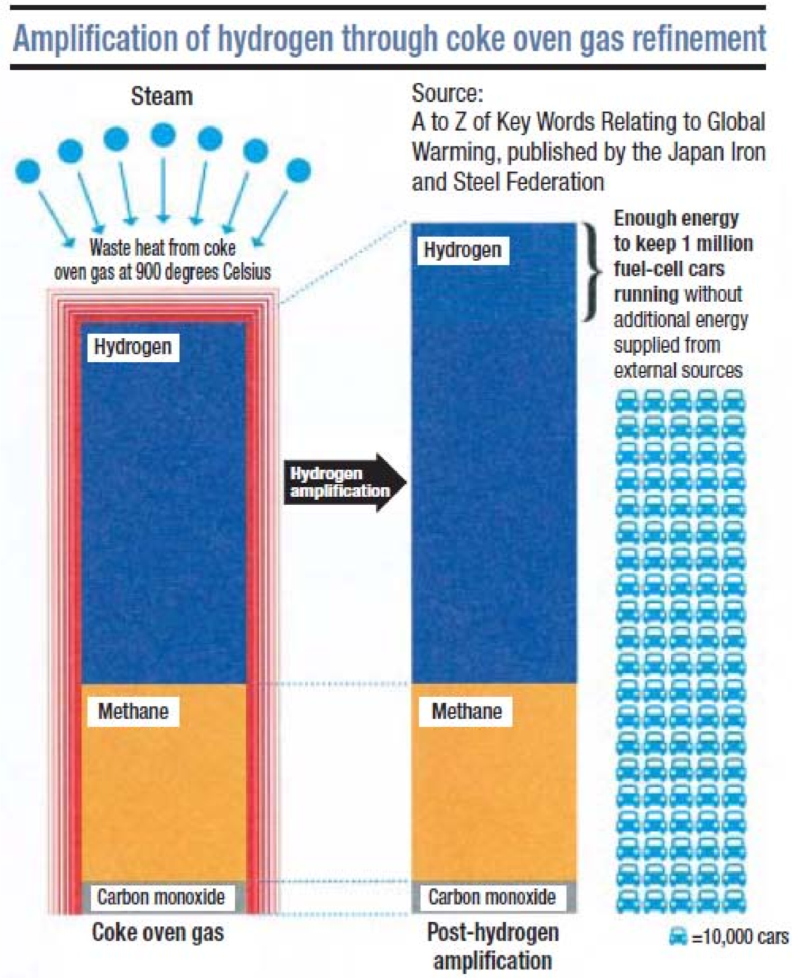

Figure 9.3: High-efficiency hydrogen production technology

Commercial Status: Emerging

Contact Information:
Japan Iron and Steel Federation, "The Voluntary Action Program of JISF"

9.5 Carbonation of Steel Slag

Description:
Carbonates of steel slag are formed when slag solidifies by absorbing CO_2. This sequesters the CO2 in the slag, which can then be used in marine applications.

Energy/Environment/Cost/Other Benefits:
- Steel slag carbonates can be used to make "marine blocks" which can improve the coastal environment by helping to grow seaweed [which improves sea surroundings]
- Absorb 1-7 weight % of CO_2 as $CaCO_3$ when forming Marine Blocks
- Marine blocks are also used for coral nursery beds, which may help to revive dead coral areas

Block Diagram or Photo:

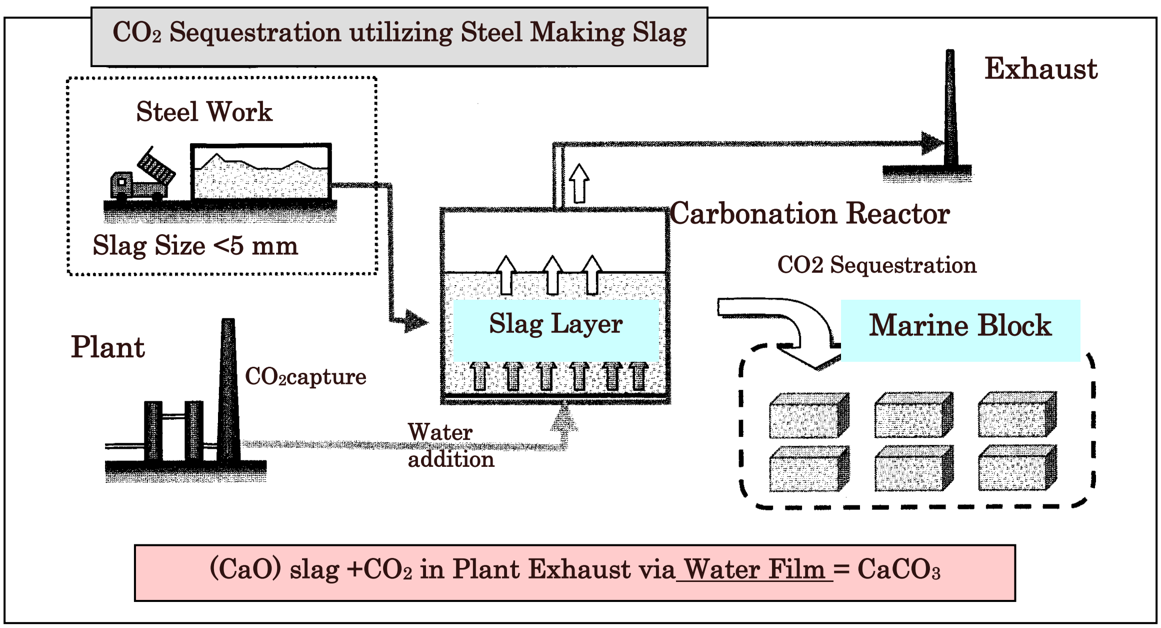

Figure 9.4: Reduction of CO_2 in exhaust gas by carbonation of steelmaking

Commercial Status: Emerging

Contact Information:
Japan Iron and Steel Federation, "The Voluntary Action Program of JISF"