# PRODUZIONE DELL'ACCIAIO

Minerali ferrosi

Rottami ferrosi

## Acciaieria



Altoforno

Convertitore

**Forni elettrici**

**Operazioni fuori forno**
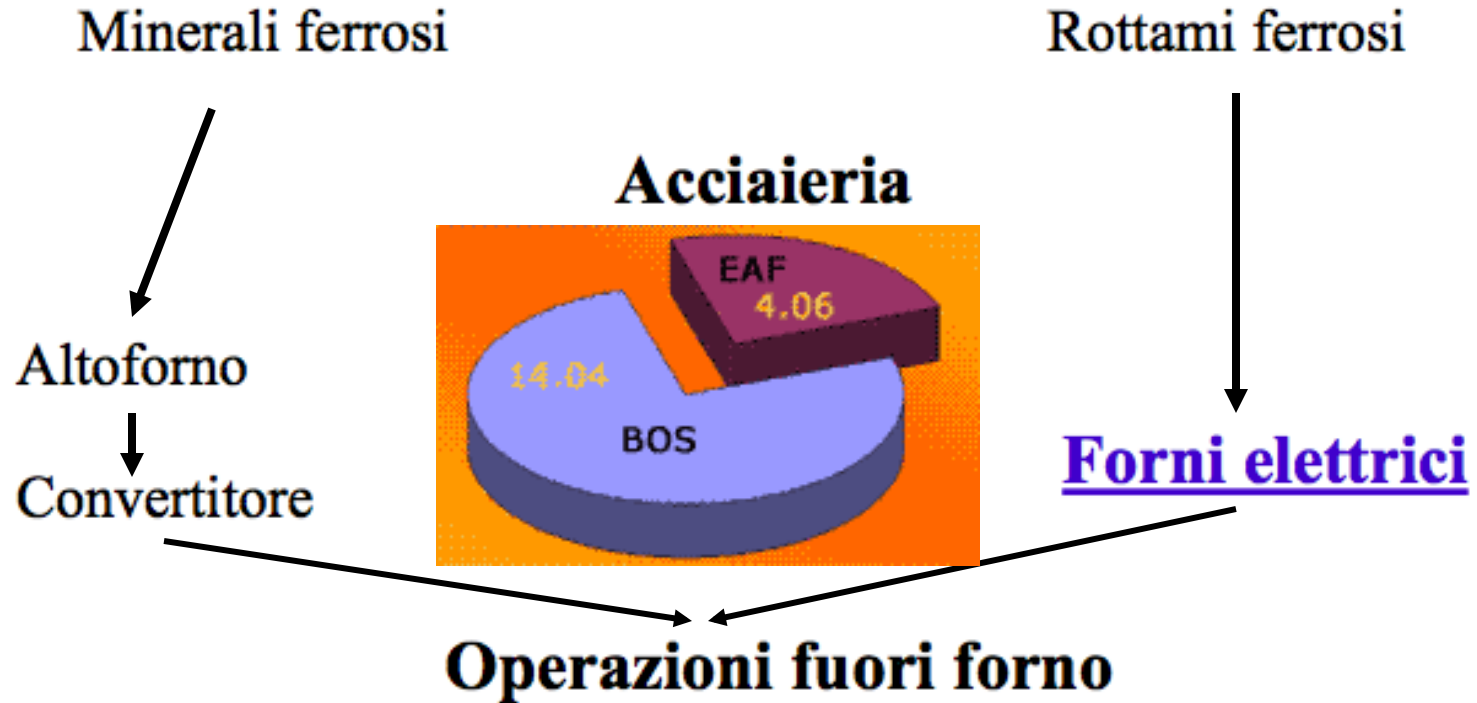
# FORNI ELETTRICI

The sequence of operations is similar to that in the **BOS** furnace, except that, after **charging**, **the charge must be melted down**. The furnace charge melts when an **electric arc passes between the electrodes and the scrap metal.** The temperature around the arc rises to $1200^{o}C$ and a 100 tonnes charge can be melted in about 60 minutes.

FURNACE OPERATIONS
The electric arc furnace operating cycle is called the tap-to-tap cycle and is made up of the following operations:
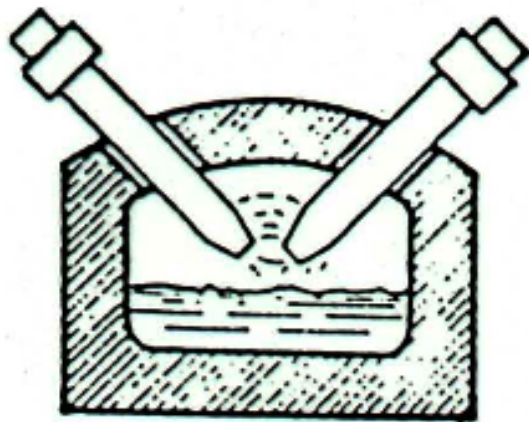
•Furnace charging
•Melting•Refining
•De-slagging
•Tapping
•Furnace turn-around

Modern operations aim for a tap-to-tap time of less than 60 minutes. Some twin shell furnace operations are achieving tap-to-tap times of 35 to 40 minutes.
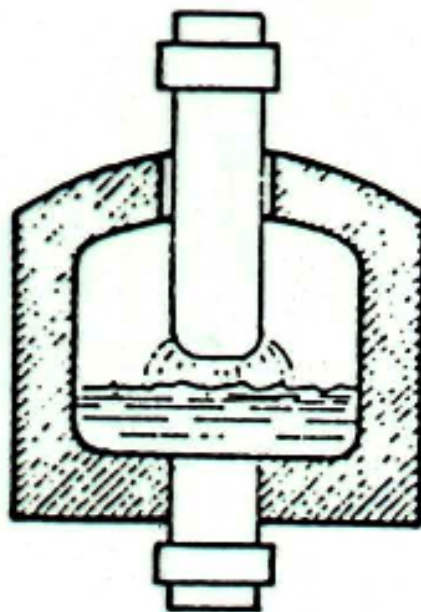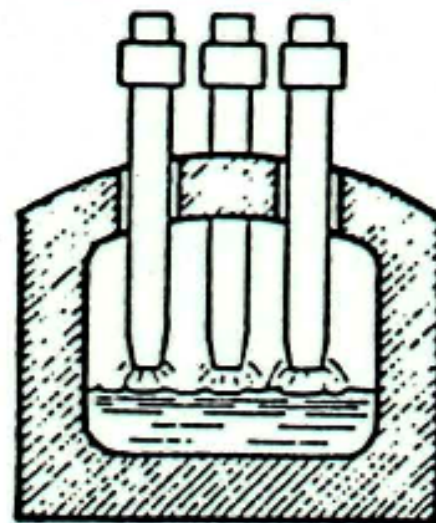
# SCHEMI DI FORNI ELETTRICI

## AD ARCO

(a) irradiante

(b) diretto con suola

conduttrice

non conduttrice

# FORNI AD ARCO DIRETTO

La potenza elettrica trasferita alla carica da fondere o al fuso mediante due o più elettrodi. Il ritorno della corrente avviene attraverso elettrodi

a) Immersi nella suola → forni a suola conduttrice.

b) Posti al di sopra del bagno → forni a suola non conduttrice.

Questi ultimi sono i più diffusi: alimentati con corrente alternata trifase (su tre elettrodi).

L'arco si stabilisce tra estremità dell'elettrodo e carica metallica che fonde per il calore irraggiato dall'arco.

**Forno:** costituito da crogiolo cilindrico (tino) chiuso sul fondo da calotta concava, in materiale refrattario su supporto in lamiera, superiormente da una volta.

le pareti del tino non lambite dal bagno e la volta superiore sono fatte di pannelli metallici tubolari raffreddati con acqua.

la carica del rottame è fatta dall'alto in quanto la volta con gli elettrodi viene sollevata → caricamento rapido, migliore distribuzione della carica.

il colaggio del fuso avviene attraverso canale di colata a seguito di inclinazione del forno, o attraverso doro posto sul fondo del tino ( forno EBT Eccentric Bottom Tapping).

questo è preferito perché previene il trascinamento delle scorie durante la colata.

la scorificazione viene effettuata  attraverso una porta opposta al canale di colata.

***Scoria***: di tipo schiumoso che si rigonfia ( da 10 a 30 cm) → elettrodo sommerso nella scoria → irraggiamento dell'arco si riduce → utilizzo di tensioni più elevate.

( si ottiene aggiungendo carbonio alla scoria e insufflando ossigeno ad alta pressione)

**Vantaggi**: 1) temperature più elevate → tempi di processo più brevi → aumento produttività.

2) minor consumo degli elettrodi

3) minor sollecitazione termica delle pareti

*Impiegati:* per produrre acciai comuni e speciali

### solo per fondere i rottami

*Capacità:* 30 – 200 t per colata; diametro del tino 7 m ( capacità di 200t)

*Elettrodi:* grafite, diametro proporzionale alla potenza del forno. Consumo 3Kg/t.
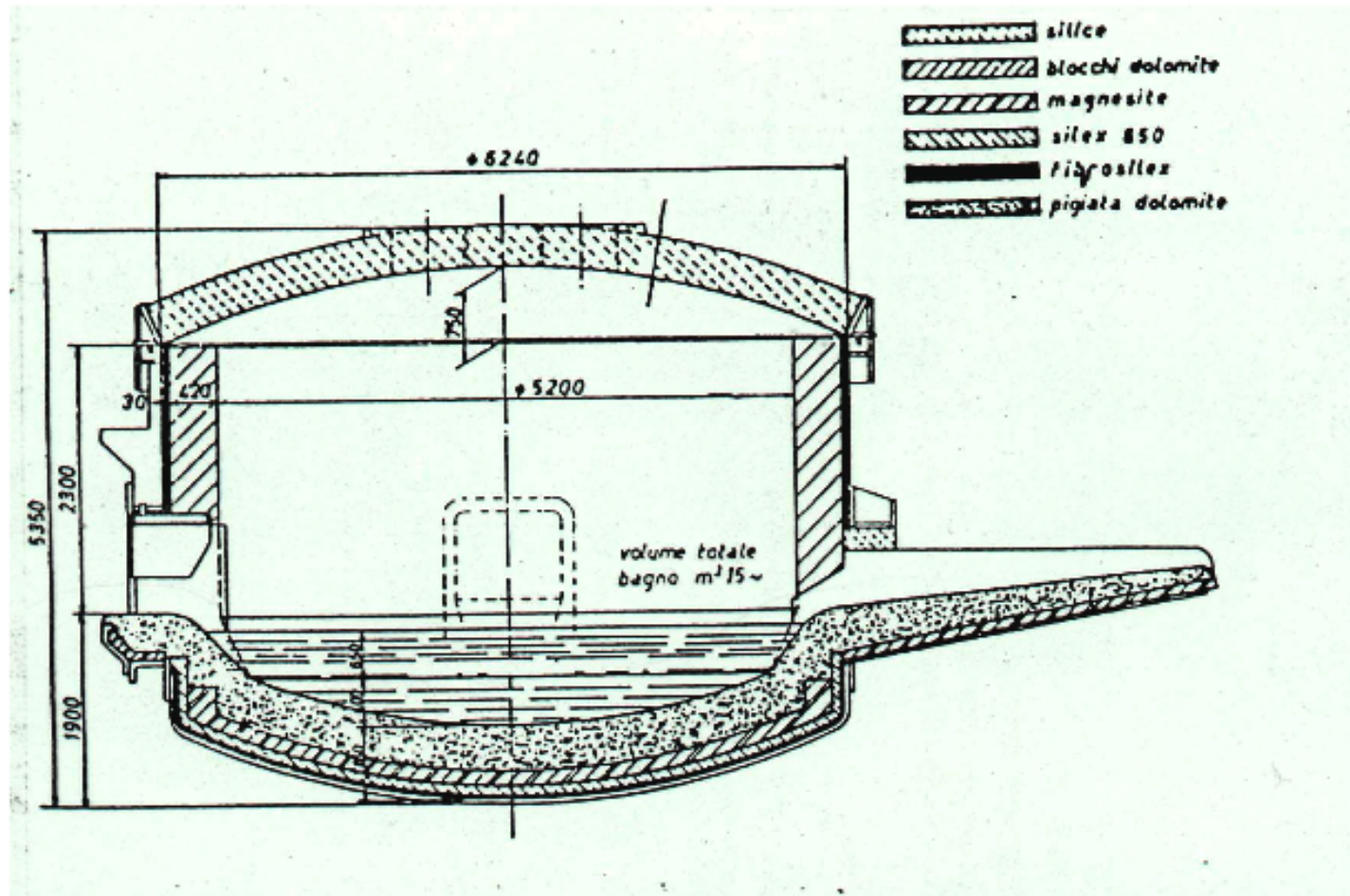
*Rivestimento:* refrattario basico (magnesite e dolomite)

Produzione di acciai in Italia (1993): 26 milioni di tonnellate

14 mil con forni elettrici ad arco (circa 58%)

1994: in Italia 63 forni ad arco

# FORNI ELETTRICI



**Rivestimento refrattario di un forno elettrico ad arco trifase da 100 t**

# FURNACE CHARGING

Preparation of the charge bucket is an important operation, not only to ensure proper melt-in chemistry but also to ensure good melting conditions.

The scrap must be layered in the bucket according to size and density to promote the rapid formation of a liquid pool of steel in the hearth while providing protection for the sidewalls and roof from electric arc radiation.

The charge can include lime and carbon or these can be injected into the furnace during the heat. Many operations add some lime and carbon in the scrap bucket and supplement this with injection.

Charging is a dead-time. Minimizing these dead-times helps to maximize the productivity of the furnace. Most operations aim for 2 to 3 buckets of scrap per heat. Some operations achieve a single bucket charge. Continuous charging operations such as CONSTEEL and the Fuchs Shaft Furnace eliminate the charging cycle.

# MELTING

The melting period is the heart of EAF operations.

Melting is accomplished by supplying energy to the furnace interior.
This energy can be electrical or chemical.

Electrical energy is supplied via the graphite electrodes and is usually the largest contributor in melting operations. Initially, an intermediate voltage is selected until the electrodes bore into the scrap. Usually, light scrap is placed on top of the charge to accelerate bore-in. Approximately 15 % of the scrap is melted during the initial bore-in period.

After a few minutes, the electrodes will have penetrated the scrap sufficiently so that a long arc (high voltage) tap can be used without fear of radiation damage to the roof. The long arc maximizes the transfer of power to the scrap and a liquid pool of metal will form in the furnace hearth

At the start of melting the arc is erratic and unstable. Wide swings in current are observed accompanied by rapid movement of the electrodes. As the furnace atmosphere heats up the arc stabilizes and once the molten pool is formed, the arc becomes quite stable and the average power input increases.

Chemical energy is be supplied via several sources including oxy-fuel burners and oxygen lances.

Oxy-fuel burners burn natural gas using oxygen or a blend of oxygen and air. Heat is transferred to the scrap by flame radiation and convection by the hot products of combustion.

In some operations, oxygen is injected via a consumable pipe lance. The oxygen reacts with the hot scrap and burns iron to produce intense heat for cutting the scrap. Once a molten pool of steel is generated in the furnace, oxygen can be lanced directly into the bath. This oxygen will react with several components in the bath including, Al, Si, Mn, P, C and Fe.

All of these reactions are exothermic and supply additional energy to aid in the melting of the scrap. The metallic oxides that are formed will end up in the slag.

The reaction of oxygen with carbon in the bath produces carbon monoxide, which either burns in the furnace if there is sufficient oxygen, and/or is exhausted through the direct evacuation system where it is burned and conveyed to the pollution control system.

Once the final scrap charge is melted, the furnace sidewalls are exposed to intense radiation from the arc. As a result, the voltage must be reduced.

Alternatively, creation of a foamy slag will allow the arc to be buried and will protect the furnace shell. In addition, a greater amount of energy will be retained in the slag and is transferred to the bath resulting in greater energy efficiency.

Once the final scrap charge is fully melted, flat bath conditions are reached. At this point, a bath temperature and sample will be taken. The analysis of the bath chemistry will allow the melter to determine the amount of oxygen to be blown during refining. At this point, the melter can also start to arrange for the bulk tap alloy additions to be made. These quantities are finalized after the refining period.

# REFINING

Refining operations in the electric arc furnace have traditionally involved the removal of P, S, Al, Si, Mn and C from the steel.

In recent times, dissolved gases, especially $H_2$ and $N_2$, been recognized as a concern.

Traditionally, refining operations were carried out following meltdown.

These refining reactions are all dependent on the availability of oxygen.

Oxygen was lanced at the end of meltdown to lower the bath carbon content to the desired level for tapping. Most of the compounds which are to be removed during refining have a higher affinity for oxygen that the carbon. Thus the oxygen will preferentially react with these elements to form oxides which float out of the steel and into the slag.

In modern EAF operations, oxygen may be blown into the bath throughout most of the heat. As a result, some of the melting and refining operations occur simultaneously.

P and S occur normally in the furnace charge in higher concentrations than are generally permitted in steel and must be removed.

Unfortunately the conditions favorable for removing P are the opposite of those promoting the removal of S.

P retention in the slag is a function of:

• bath temperature,

• the slag basicity

• FeO levels in the slag.

At higher temperature or low FeO levels, the P will revert from the slag back into the bath.
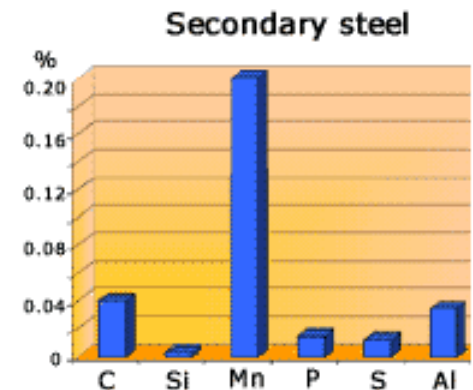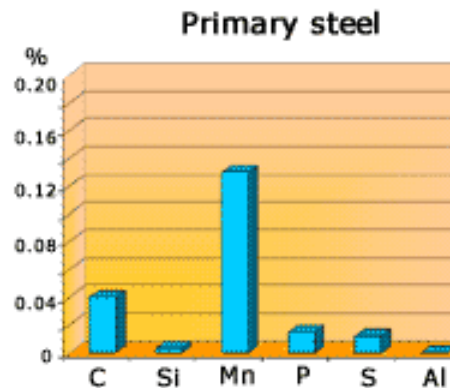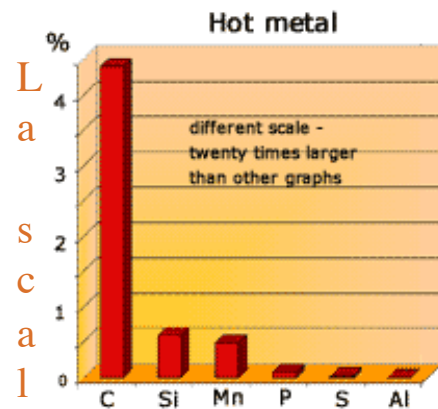
P removal is usually carried out as early as possible in the heat. Hot heel practice is very beneficial for P removal because $O_2$ can be lanced into the bath while its temperature is quite low.

Early in the heat the slag will contain high FeO levels carried over from the previous heat thus aiding in P removal. High slag basicity (i.e. high lime content) is also beneficial for P removal but care must be taken not to saturate the slag with lime. This will lead to an increase in slag viscosity, which will make the slag less effective. Sometimes fluorspar is added to help fluidize the slag. Stirring the bath with inert gas is also beneficial because it renews the slag/metal interface thus improving the reaction kinetics.

In general, if low P levels are a requirement for a particular steel grade, the scrap is selected to give a low level at melt-in. The partition of P in the slag to P in the bath ranges from 5 to 15. Usually the P is reduced by 20 to 50 % in the EAF.

S is removed mainly as a sulfide dissolved in the slag.

The S partition between the slag and metal is dependent on slag chemistry and is favored at low steel oxidation levels.

Removal of S in the EAF is difficult especially given modern practices where the oxidation level of the bath is quite high.

Generally the partition ratio is between 3 and 5 for EAF operations. Most operations find it more effective to carry out deSization during the reducing phase of steelmaking. This means that deSization is performed during tapping (where a calcium aluminate slag is built) and during ladle furnace operations.

For reducing conditions where the bath has a much lower oxygen activity, distribution ratios for S of between 20 and 100 can be achieved.

Control of the metallic constituents in the bath is important as it determines the properties of the final product.

Usually, the melter will aim at lower levels in the bath than are specified for the final product.

Oxygen reacts with Al, Si and Mn to form metallic oxides, which are slag components. These metallics tend to react with $O_2$ before the C.

They will also react with FeO resulting in a recovery of iron units to the bath. For example:

$$Mn + FeO = MnO + Fe$$
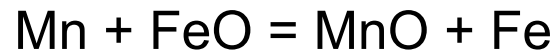
Manganese will typically be lowered to about 0.06 % in the bath.

The reaction of C with $O_2$ in the bath to produce CO is important as it supplies a less expensive form of energy to the bath, and performs several important refining reactions.

In modern EAF operations, the combination of $O_2$ with C can supply between 30 and 40 % of the net heat input to the furnace.

Evolution of CO is very important for slag foaming. Coupled with a basic slag, CO bubbles are tapped in the slag causing it to "foam" and helping to bury the arc. This gives greatly improved thermal efficiency and allows the furnace to operate at high arc voltages even after a flat bath has been achieved. Burying the arc also helps to prevent $N_2$ from being exposed to the arc where it can dissociate and enter into the steel.

If the CO is evolved within the steel bath, it helps to strip $N_2$ and $H_2$ from the steel.

$N_2$ levels in steel as low as 50 ppm can be achieved in the furnace prior to tap.
At 1600 C, the maximum solubility of $N_2$ in Fe is 450 ppm. Typically, the $N_2$ levels in the Fe following tapping are 80 - 100 ppm.

Decarburization is also beneficial for the removal of $H_2$.
It has been demonstarted that decarburizing at a rate of 1 % per hour can lower $H_2$ levels in the steel from 8 ppm down to 2 ppm in 10 minutes.

At the end of refining, a bath temperature measurement and a bath sample are taken. If the temperature is too low, power may be applied to the bath. This is not a big concern in modern meltshops where temperature adjustment is carried out in the ladle furnace.

# DE - SLAGGING

De-slagging operations are carried out to remove impurities from the furnace. During melting and refining operations, some of the undesirable materials within the bath are oxidized and enter the slag phase.

It is advantageous to remove as much P into the slag as early in the heat as possible (i.e. while the bath temperature is still low). The furnace is tilted backwards and slag is poured out of the furnace through the slag door. **Removal of the slag eliminates the possibility of P reversion**.

During slag foaming operations, C may be injected into the slag where it will reduce FeO to metallic iron and in the process produce CO which helps foam the slag. If the high P slag has not been removed prior to this operation, P reversion will occur.

# TAPPING

Once the desired steel composition and temperature are achieved in the furnace, the tap-hole is opened, the furnace is tilted, and the steel pours into a ladle for transfer to the next batch operation.

During the tapping process bulk alloy additions are made based on the bath analysis and the desired steel grade.

De-oxidizers may be added to the steel to lower the $O_2$ content prior to further processing. This is commonly referred to as "blocking the heat" or "killing the steel".

Common de-oxidizers are Al or Si in the form of ferrosilicon or silicomanganese.

Most carbon steel operations aim for minimal slag carry-over. A new slag cover is "built" during tapping. For ladle furnace operations, a calcium aluminate slag is a good choice for sulfur control. Slag forming compounds are added in the ladle at tap so that a slag cover is formed prior to transfer to the ladle furnace. Additional slag materials may be added at the ladle furnace if the slag cover is insufficient.

# FURNACE TURN-AROUND

Furnace turn-around is the period following completion of tapping until the furnace is recharged for the next heat.

During this period, the electrodes and roof are raised and the furnace lining is inspected for refractory damage. If necessary, repairs are made to the hearth, slag-line, tap-hole and spout.

Many operations now switch out the furnace bottom on a regular basis (2 to 6 weeks) and perform the hearth maintenance off-line. This reduces the power-off time for the EAF and maximizes furnace productivity.

Furnace turn-around time is generally the largest dead time (i.e. power off) period in the tap-to-tap cycle. With advances in furnace practices this has been reduced from 20 minutes to less than 5 minutes in some newer operations.

# Furnace Heat Balance

To melt steel scrap, it takes a theoretical minimum of 300 kWh/ton.

To provide superheat above the melting point of 1600 C requires additional energy and for typical tap temperature requirements, the total theoretical energy required usually lies in the range of 350 to 370 kWh/ton.

However, EAF steelmaking is only 55 to 65 % efficient and as a result the total equivalent energy input is usually in the range of 560 to 680 kWh/ton for most modern operations.

This energy can be supplied from a variety of sources. The energy distribution is highly dependent on local material and consumable costs and is unique to the specific meltshop operation.

# THE FUTURE

The global output of steel from EAF furnaces is increasing.

Many countries that cannot make iron by the traditional **Blast Furnace** route but have sufficient supplies of scrap have developing steel industries based on the EAF process

The output of iron from Blast Furnaces is likely to decline in the future because of diminishing supplies of coking coal and other raw materials.

This means that steel recycling in the EAF will grow in importance.