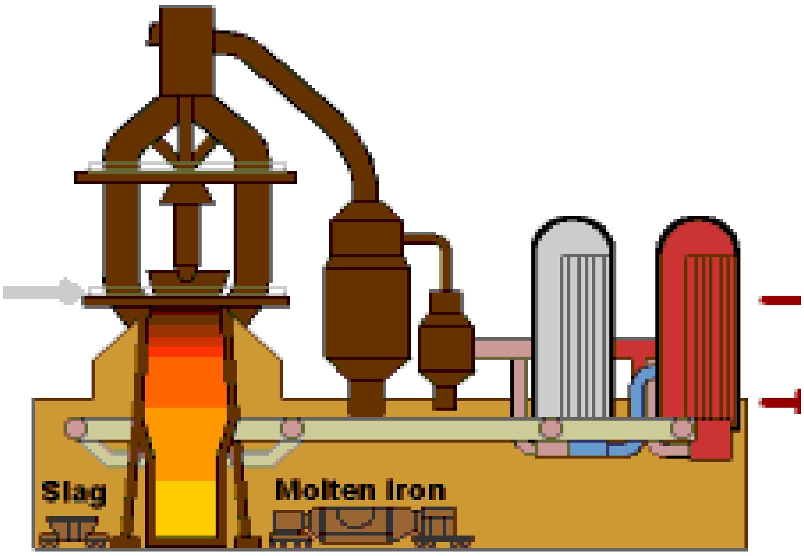
IRON PRODUCTION

The Blast Furnace

The purpose of a blast furnace is to chemically reduce and physically convert iron oxides into liquid iron called "hot metal". A blast furnace is something like 60m high and 7.5m in diameter at the base and may produce 2000 to 10 000 tonnes of iron per day. Since a refractory lining lasts for several years, it is only at the end of this period that the blast-furnace shut down; otherwise it works a 365-day year.



Blast Furnace
Produces molten pig iron from iron ore.

Furnace Charge (Iron Ore)

Iron oxides can come to the blast furnace plant in the form of raw ore, pellets or sinter. This ore is either Hematite (Fe_2O_3) or Magnetite (Fe_3O_4) and the iron content ranges from 50% to 70%.This iron rich ore can be charged directly into a blast furnace without any further processing. Iron ore that contains a lower iron content must be processed or beneficiated to increase its iron content.

Pellets are produced from this lower iron content ore. This ore is crushed and ground into a powder so the waste material called gangue can be removed. The remaining iron-rich powder is rolled into balls and fired in a furnace to produce strong, marble-sized pellets that contain 60% to 65% iron. Sinter is produced from fine raw ore, small coke, sand-sized limestone and numerous other steel plant waste materials that contain some iron.

Furnace Charge (Coke)

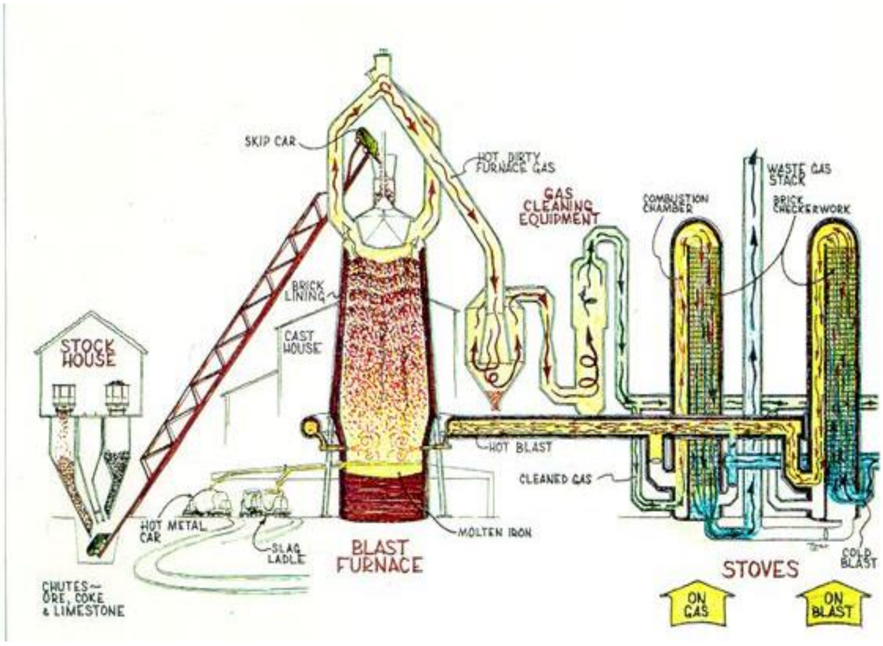
The coke is produced from a mixture of coals. The coal is crushed and ground into a powder and then charged into an oven. As the oven is heated the coal is cooked so most of the volatile matter such as oil and tar are removed. The cooked coal, called coke is cooled and screened into pieces ranging from one inch to four inches. The coke contains 90 to 93% carbon, some ash and sulfur but compared to raw coal is very strong. The strong pieces of coke with a high energy value provide permeability, heat and gases which are required to reduce and melt the iron ore, pellets and sinter.

Furnace Charge (Limestone)

The final raw material in the ironmaking process in limestone. This flux can be pure high calcium limestone, dolomitic limestone containing magnesia or a blend of the two types of limestone. Since the limestone is melted to become the slag which removes sulfur and other impurities, the blast furnace operator may blend the different stones to produce the desired slag chemistry that create optimum properties such as has a low melting point and a high fluidity.

The Process

Iron ore, coke and limestone are dumped into the top, and preheated air is blown into the bottom. The raw materials require 6 to 8 hours to descend to the bottom of the furnace. When the metal is melted it falls to the bottom of hearth. Limestone combines with the earthy matter in the iron ore and forms slag.



When the temperature is very high this slag liquefies and forms a layer on top of molten metal. (i.e. the slag is less dense than the molten metal). At intervals of several hours, the furnace team opens both the slag hole and the tap hole, in order to run off first slag and then molten iron. The holes are then plugged with clay.

All of the raw materials are stored in an ore field and transferred to the stockhouse before charging. Once these materials are charged into the furnace top, they go through numerous chemical and physical reactions while descending to the bottom of the furnace.

The smelting operation involves two main reaction.

(1) The chemical reduction of iron ore by carbon monoxide gas arising from the burning coke:

Towards	**300 °C**	**$3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$**
Towards	**600 °C**	**$Fe_3O_4 + CO = 3FeO + CO_2$**
Towards	**1000 °C**	**$FeO + CO = Fe + CO_2$**

Processed ore, coke and limestone are charged to the furnace through the double-bell gas-trap system; whilst a blast of heated air is blown in through the tuyers near the hearth of the furnace.

(2) Lime (from limestone added with the furnace charge) combines with many of the impurities and earthy waste contained in the ore to form a fluid slag which will run from the furnace. The slag is broken up and used for road-making or as a concrete aggregate

Another product of the ironmaking process, in addition to molten iron and slag, is hot dirty gases. This gas has a considerable energy value so it is burned as a fuel in the "hot blast stoves" which are used to preheat the air entering the blast furnace to become "hot blast". Any of the gas not burned in the stoves is sent to the boiler house and is used to generate steam which turns a turbo blower that generates the compressed air is air known as "cold blast" that comes to the stoves.

The molten iron is either cast into 'pigs' for subsequent use in an iron foundary or transferred (still molten) to the steel making plant.

In the case of modern blast furnace, an output of 1 ton of pig iron would involve the following materials.

Charge		**Products**	
ore (say 50% iron)	2 tonnes	pig iron	1 ton
limestone	1 ton	Slag	1.1 tonnes
coke	1 ton	furnace gas	4 000 m^3
air	3 000 m^3		

One feature of the above table is the vast amount of furnace gas passing along the 'down-comer' each day. The gas contains a large amount of carbon monoxide and therefore has a considerable calorific value. This gas can be used for raising electric power and to heat the air blast.

STEEL MAKING

The metal that leaves the Blast Furnace contains between 4% and 5% of carbon. This much carbon makes a very hard but brittle metal which is not much use. The next step in the production of steel is to reduce the levels of carbon and other impurity elements in the hot metal.

To make steel from iron it is necessary to reduce the carbon content. Here are the approximate percentages for carbon, silicon, sulphur, phosphorus and manganese in basic iron and in mild steel:

	Basic iron	Mild steel
Carbon	3.5	0.15
Silicon	0.85	0.03
Sulphur	0.08	0.05
Phosphorus	1.6	0.05
Manganese	1.0	0.5

As shown in the table, the other elements as well as carbon have been reduced. These elements are called ***impurities*** in the metal. How are they reduced? The process by which they are reduced is called oxidation.

Effect of Trace Elements on Carbon Steel

- 0-1% manganese: reacts with sulfur, to produce MnS soft inclusions increased yield strength.

- 0-0.05% sulfur: if insufficient manganese, sulfur will react with iron at grain boundaries, cracking during working.

- 0-0.04% phosphorous: forms brittle Fe3P compound.

- 0-0.03% silicon: forms silicate inclusions (SiO2) but has little effect on properties

Steel Making Processes

- **Basic Oxygen Steelmaking (BOS)**
- **Electric Arc Furnace**
- **The Bessemer Process**

The first two methods of making steel are dominant in modern steel industries all over the world.

The Bessemer Process

In this process the impurities in the metal are burnt away by blowing air through molten iron. The oxygen in the air combines with some of the iron to produce iron oxide. The iron oxides 'oxidises' the silicon and manganese and these together with iron oxide form slag. The iron oxide also oxidises the carbon, which forms carbon monoxide and carbon dioxide gas. This is why the process is called 'oxidation'. When these impurities have formed slag or gas they can be separated from the iron. The metal that is poured away is steel. In the Bessemer process, the impurities, mainly carbon, phosphorus, silicon and manganese act as a fuel; and so the range of compositions of pig iron is limited, because sufficient impurities are necessary in order that the charge does not blow cold from lack of fuel. Since the air blast contains only 20% of oxygen by volume, much valuable heat is carried out from the charge by the 80% nitrogen also present.

Basic Oxygen Process

Basic Oxygen Steelmaking (**BOS**) makes steel from Blast Furnace iron and small amounts of scrap metal In this process no heat is carried out by useless nitrogen and a charge containing up to 40% scrap can be used.

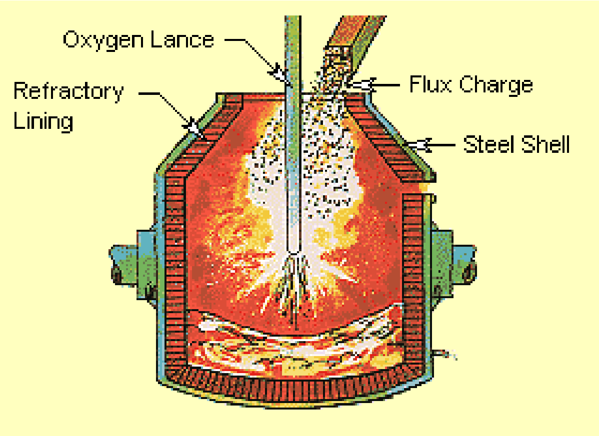


Figure. Manufacture of steel by the basic oxygen process.

There are three main stages in the operation of the furnace

- **Charging the furnace**
- **Blowing**
- **Tapping the furnace**

Charging the furnace: The BOS converter is **charged** first with **scrap**. This is used as a coolant. It helps to control the very high temperatures produced by the violently **exothermic** reactions in the furnace. After the scrap, three or four times as much **hot metal** (up to 300 tonnes) is poured into the furnace from a **ladle**.

Blowing: After charging, the furnace is blown by **blasting oxygen** through a lance that is lowered into the molten metal. The furnace needs no heating because the oxygen combines very exothermically with the impurity elements, carbon, silicon, manganese and phosphorus. Carbon is oxidised to carbon monoxide and much of the carbon in the metal escapes as this gas. The other impurity elements also form oxides. These are acidic and are separated from the metal by adding basic calcium oxide (lime) to the furnace. This combines with the oxides and removes silicon, manganese and phosphorus in a slag.

Tapping the furnace: After the **blow** has continued for about 20 minutes, the metal is **sampled**. The BOS process is now complete and the furnace can be **tapped.** The slag is run off first and any adjustments made to the carbon content of the charge which is then transferred to a ladle.

Electric Arc Furnace

Originally electric arc steel making processes were used for the manufacture of high grade tool and alloy steels but are now widely employed both in the treatment of 'hot metal' and of process scrap as well as scrap from other sources. The high cost of electricity is largely offset by the fact that cheap scrap can be processed economically to produce high-quality steel.

Since electricity is perfectly clean fuel no impurities are transmitted to the charge. Sulphur, which was virtually impossible to eliminate in either Bessemer or basic-oxygen processes can be effectively reduced to extremely low limits in the electric arc process.

The furnace employs carbon electrodes which strike an arc on to the charge. Lime and mill scale are added in order to produce a slag which removes most of the carbon, silicon, manganese and phosphorus.

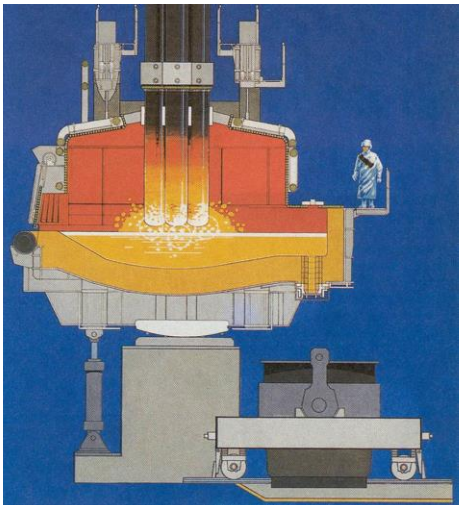


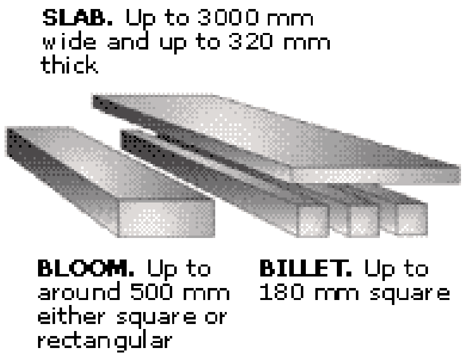
Figure. The electric arc furnace for steel making

During the melt-down process, temperatures in the arc reach as high as 3500 °C, and in the steel bath as high as 1800 °C. The high temperatures also enable the dissolution of difficult-to-melt scrap alloy constituents. Additional injection of oxygen or of other fuel-gas mixtures accelerates the melt-down process. Once the required chemical composition and temperature of the steel have been attained, the furnace is emptied into a ladle by tilting. An arc furnace can produce any steel grade, completely regardless of the charge.

SOLIDIFICATION OF STEEL

Regardless of the method by which the steel is made, it must undergo a change of state from liquid to solid before it becomes a usable product. The liquid can be converted directly into finish-shape steel casting or can be solidified into a form suitable for further processing. In most cases the latter option is exercised through either ***continuous casting*** or the forming of ***ingots***, these shapes being the feed stock material for subsequent forging and rolling operations.

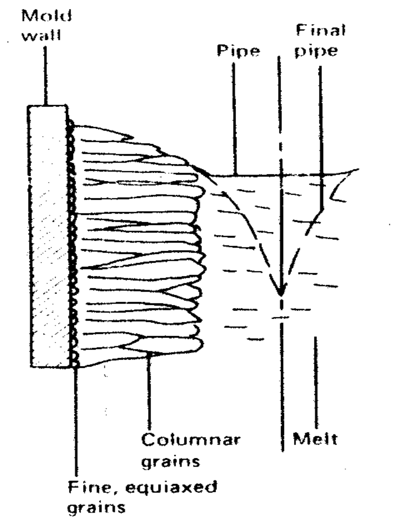
Cast bodies of circular, octagonal, or round-cornered square cross sections are called ingots when their diameter or side dimensions is about 200 mm or greater, and are called billets when smaller. Bodies of rectangular cross section are called slabs.



Ingot moulds

Ingot casting, which involves pouring the steel portion by portion into permanent (ingot) moulds, is gradually decreasing in importance and used only for high-weight pieces that are to be processed further by forging.

Steel is cast into large, iron ingot moulds holding several tonnes of metal. These moulds generally stand on a flat base and are tapered upwards very slightly so that the mould can be lifted clear of the solid ingot.



Better quality, i.e. better surface, less slag and gas entrapment, is often obtained by bottom pouring. as illustrated in Figure, the bottom of several ingot moulds is connected to a central pouring ingot by ceramic tile tunnels.

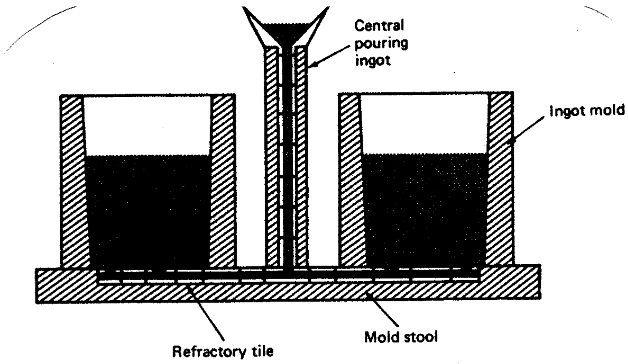
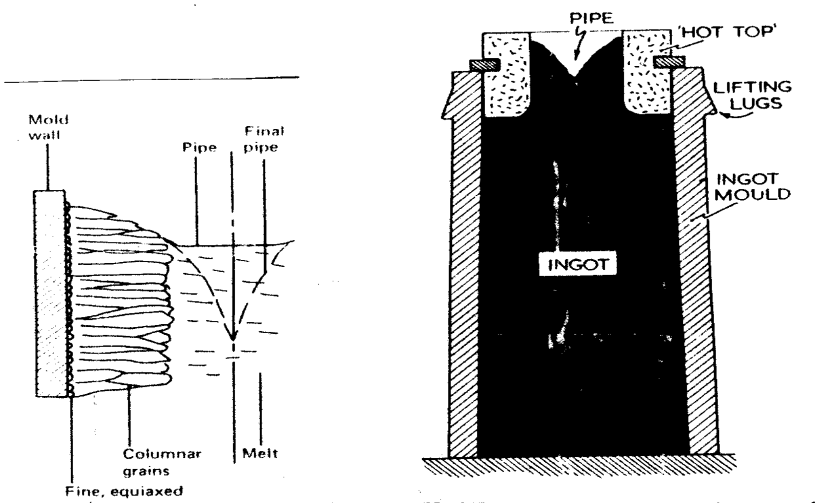


Figure. Pouring of ingots by the bottom pouring process.

Hot metal is poured into the center ingot and as the level rises, hot metal is conveyed through the tunnels to fill the outer moulds. Contaminants rise to the top and remain trapped in the central pouring ingot. Thus, the bottom poured ingots tend to be of rather high quality.

In ingots, solidification proceeds inward from the mould walls and upward from the bottom. Shrinkage takes the form of a pipe coming in from the top, as illustrated in Figure. Since the pipe surface has been exposed to the atmosphere at elevated temperature, oxides and surface contaminants form that would prevent the metal from welding back together during subsequent processing. That portion of ingot containing the pipe must be recycled as scrap.

One procedure for reducing the amount of pipe is to use hot top or exothermic topping on the top of ingot mould. If heat is retained at the top, the liquid reservoir at the end of solidification is more of a uniform layer and the depth of shrinkage is minimised.



A typical mould for producing steel ingots. The 'hot top' restricts the formation of the 'pipe' which is caused by contraction of the metal as it solidifies.

Figure. Section of ingot showing a pipe (top) and segregation (dark areas).

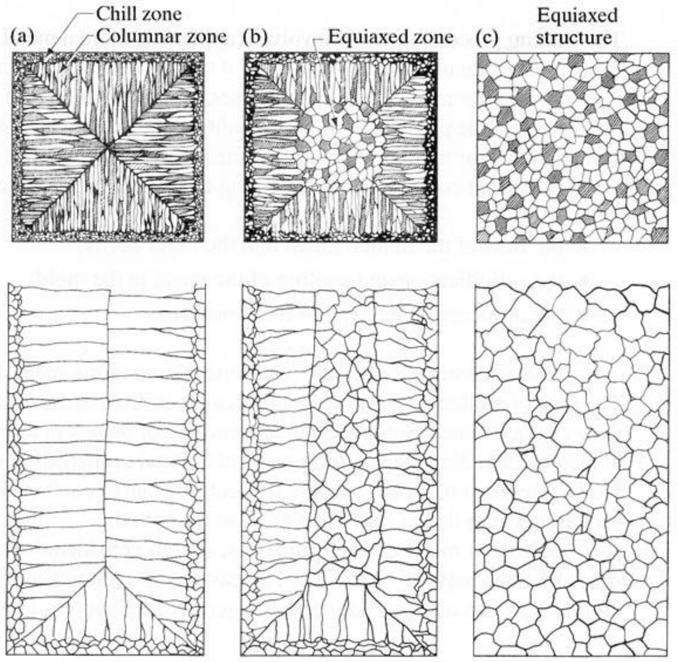


Figure. Schematic illustration of three **cast structures** solidified in a square mold: (a) pure metals; (b) solid solution alloys; and © structure obtained by using nucleating agents. *Source*: G. W. Form, J. F. Wallace, and A. Cibula

Degassification of Ingots

Pores that are totally internal can be welded shut during subsequent hot forming, but if they are exposed to air at elevated temperatures, the pore surfaces oxidize and will not weld. Cracks and internal defects may then appear in the finished product.
Where high-quality steel is desired or where subsequent deformation may be inadequate to produce welding of the pores, the metal is usually fully deoxidized (or killed) to produce killed steel.

Aluminum, ferromanganese or ferro silicon is added to the molten steel while it is still in the ladle to provide material with a higher affinity for oxygen than carbon. The rejected oxygen simply reacts to produce solid metallic oxides dispersed throughout the structure.

High carbon steels and alloy steels are often fully killed. For steels with a lower carbon content, a partial deoxidation may be employed to produce a semi-killed steel. Enough deoxidant is added to partially suppres bubble evolution, but not enough to completely eliminate the effect of oxygen. Some pores still fom in the center of the ingot, their volume serving to canceal some of the solidification shrinkage, thus reducing the extend of piping and scrap generation.

Continuous casting

The modern steel industry uses continuous casting, which is more efficient. This technique allows molten steel from the ladle to be cast directly into the basic shape that the customer wants. By adjusting the water-cooled moulds in the continuous caster, steel sections can be produced in the three basic shapes shown on the right: slabs, blooms and billets.

Continuous casting processes have been developed to overcome a number of ingot-related difficulties, such as

- piping,
- entrapped slag and
- structure variation

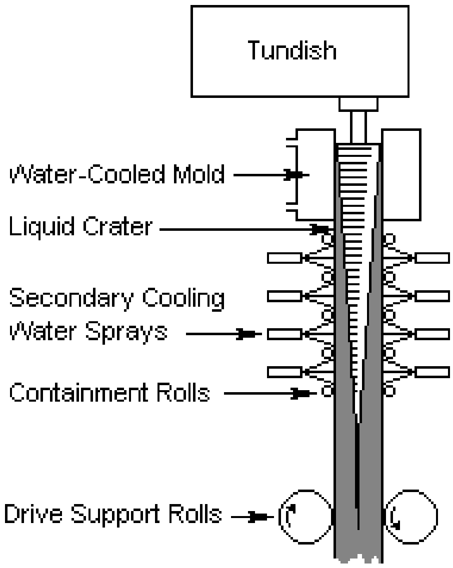
In other words, the products have

- improved surfaces,
- more uniform chemical composions and
- fewer oxide inclusions.

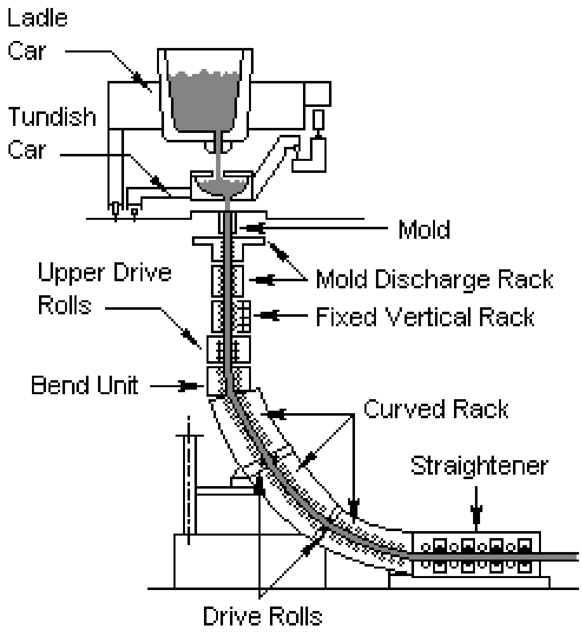
From production view point, it eliminates:

- Pourinig into moulds
- Stripping the moulds from the solidified metal
- Cost energy and scrap are all significantly reduced.

Following figure illustrates one of the most common continuous casting procedures, in which molten metal flows from a ladle, through a tundish, into a bottomless, water cooled mould, usually made of copper. The material is then further cooled by direct water sprays to ensure complete solidification.



The cast solid is then either bent and fed horizontally through a short reheat furnace before rolling or is cut to the desired lengths.



Mould shape, and thus the shape of the cast product, may vary so that products may be cast with cross sections closer to the desired final shape. Continuous casting can also be used to produce long lengths of special cast section i.e. only a single mould is required to produce a large number of pieces such as gears.

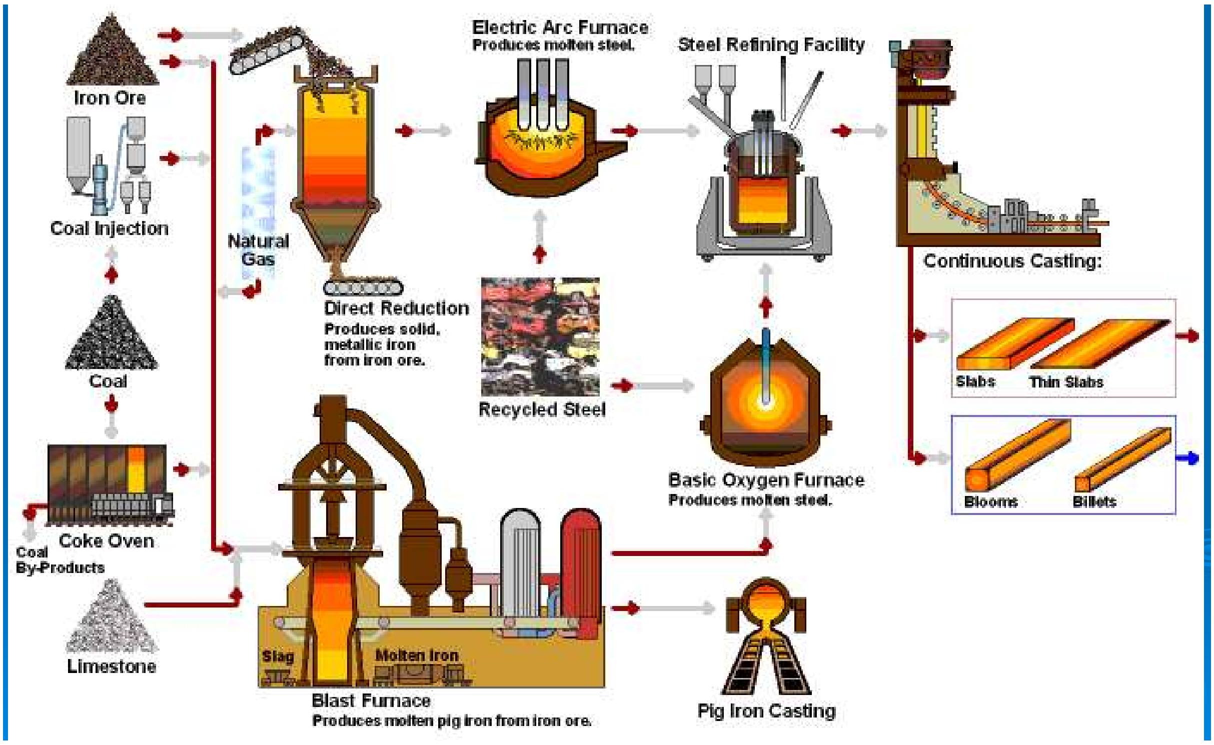


Figure. Steel making flow line

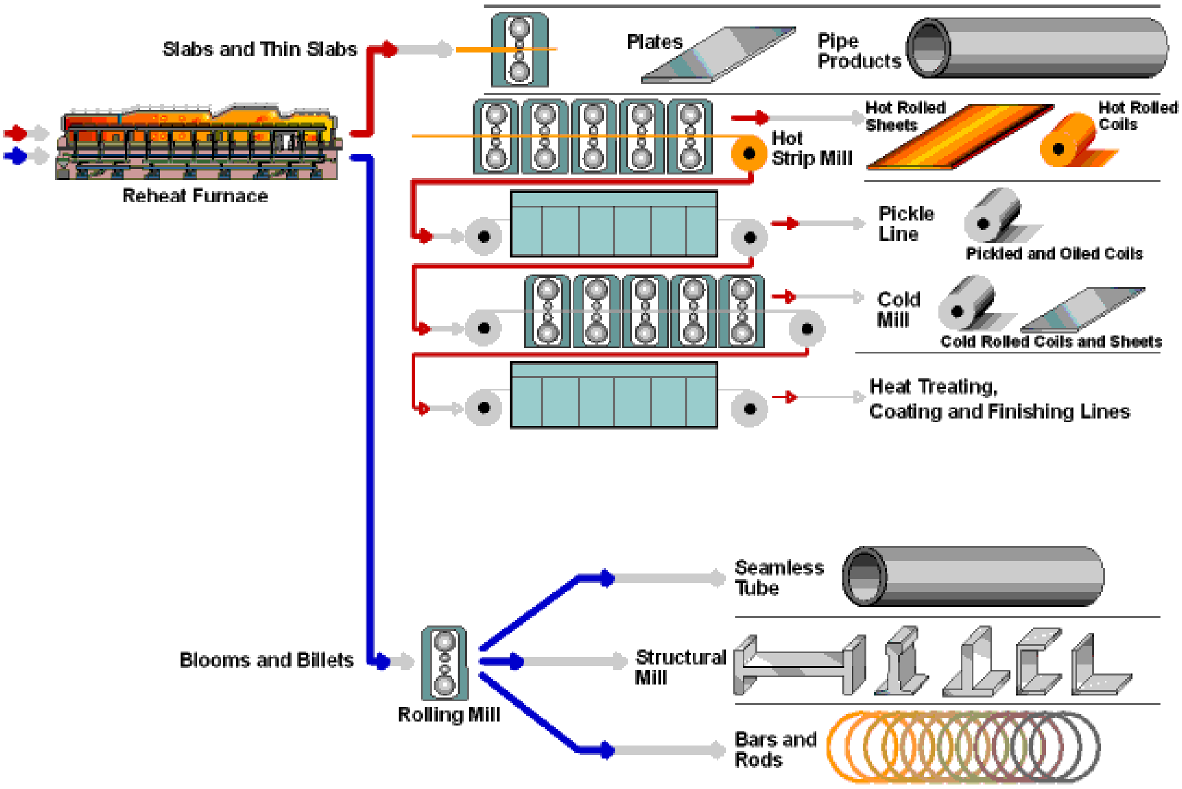


Figure. Steel finishing flow line