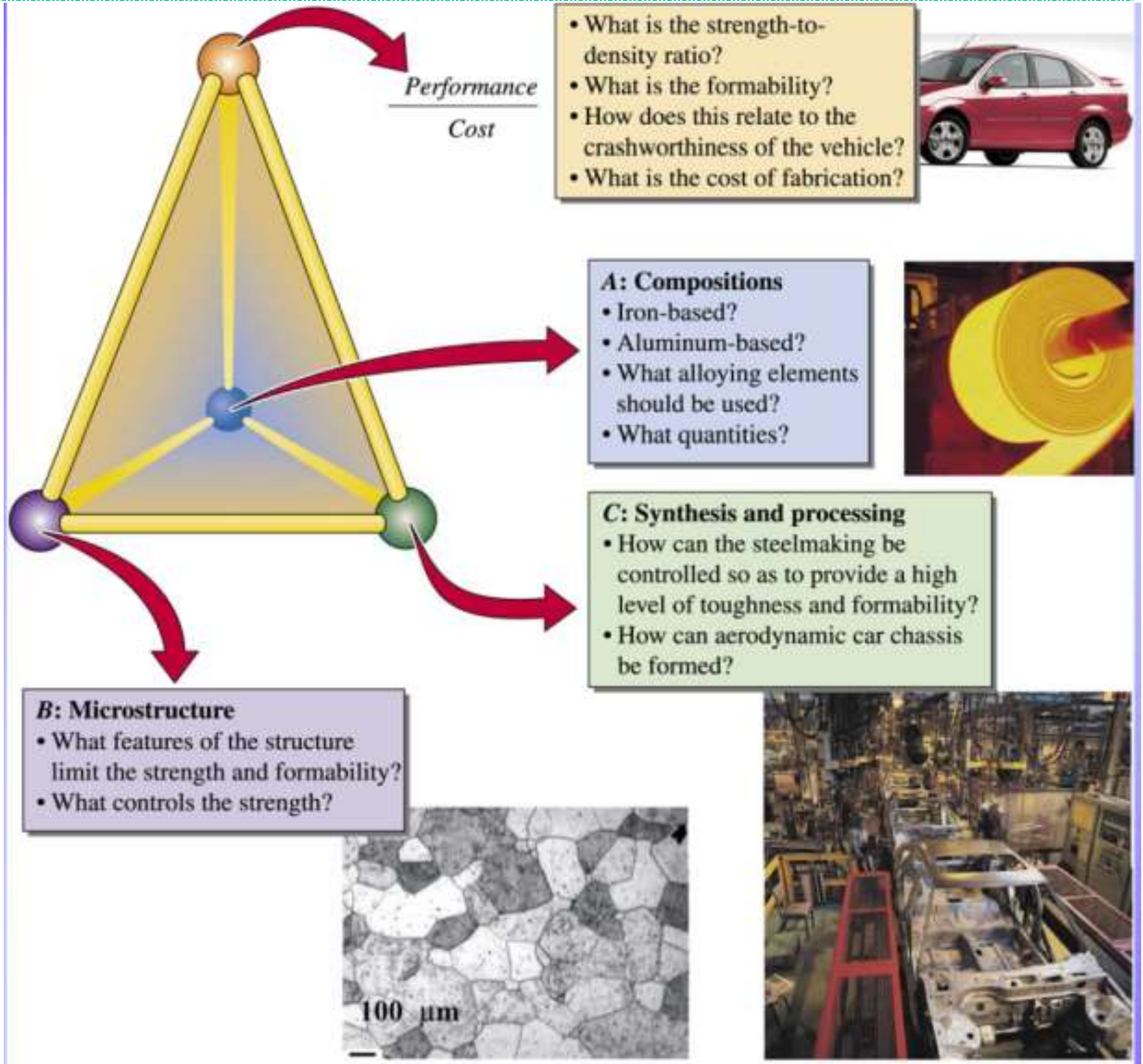
What is Materials Science and Engineering?

- **Materials Science –** emphasis on relationships between synthesis and processing, structure and properties
- **Materials Engineering –** emphasis on transforming materials into useful devices or structures.



Why do engineers need to study materials engineering?

- **Design and innovation**
- **Materials selection**
- **Improvement**
- **Failure analysis**

Production of Iron & Steel

Learning objectives:

- **Introduction,**
- **Production of Pig – Iron process,**
- **Steel Production Process,**
  - **Bessemer**
  - **Open hearth**
  - **LD (Linz Donawitz) converters**
  - **Electrical - Ultra High Power (UHP) electric furnace**
  - **the ladle steelmaking processes and continuous casting.**
- **Steel - introduction**
    - **Carbon steel**
    - **Classification of carbon Steel**

Production of Iron & Steel

- **What is Iron?**
  - **Iron is a chemical element. It is a strong, hard, heavy gray metal,**
  - **Iron is produced by melting iron ore (mineral compounds in the earth's crust – 5% of the Earth's crust is iron) and removing impurities.**
    - **Pig iron**
    - ***Wrought iron***

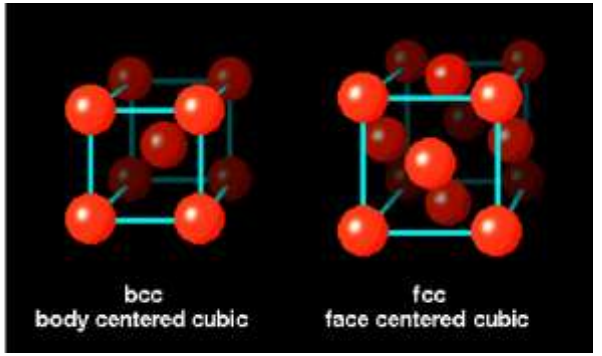
- **What is steel?**
  - **Steel is simply a purer form of iron with lower carbon content.**
  - **Steel can be produced from molten iron ore with blast of air (BOF), Electric furnace, Bessemer converter.**

Introduction - Iron and steel

- **Applications:**
  - **Cutting tools, pressure vessels, bolts, hammers, gears, cutlery, jet engine parts, car bodies, screws, concrete reinforcement, 'tin' cans, bridges…**
- **Why? (advantages)**
  - **Ore is cheap and abundant**
  - **Processing techniques are economical (extraction, refining, alloying, fabrication)**
  - **High strength**
  - **Very versatile metallurgy – a wide range of mechanical and physical properties can be achieved, and these can be tailored to the application**
- **Disadvantages:**
  - **Low corrosion resistance**
  - **High density: 7.9 g cm^{-3}**

Introduction - Iron and steel

- Iron is allotropic / polymorphic
  - i.e. exhibits different crystal structures at different temperatures
- Most importantly: bcc ⟺ fcc transformation at 912°C (for pure iron)



- Solubility of carbon:
  - in ferrite (α-iron, bcc): 0.02 wt%
  - austenite (γ-iron, fcc): 2.1 wt%
- What happens to carbon when crystal structure transforms from fcc to bcc? ---

Production of Pig – Iron process

1. Raw materials procurement

Coal

Fuel oil

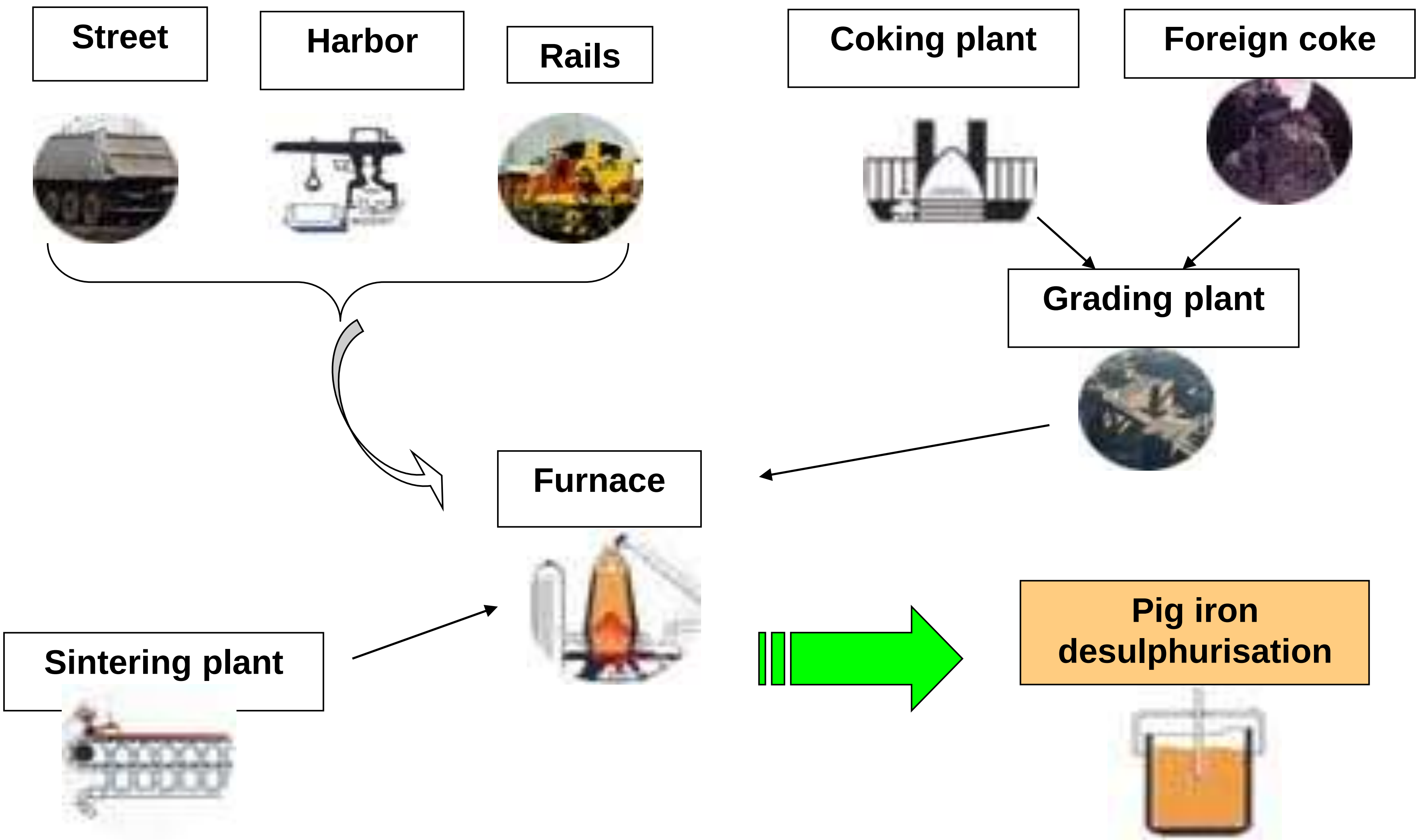
Pallets lump ore

Limestone

Alloying medium

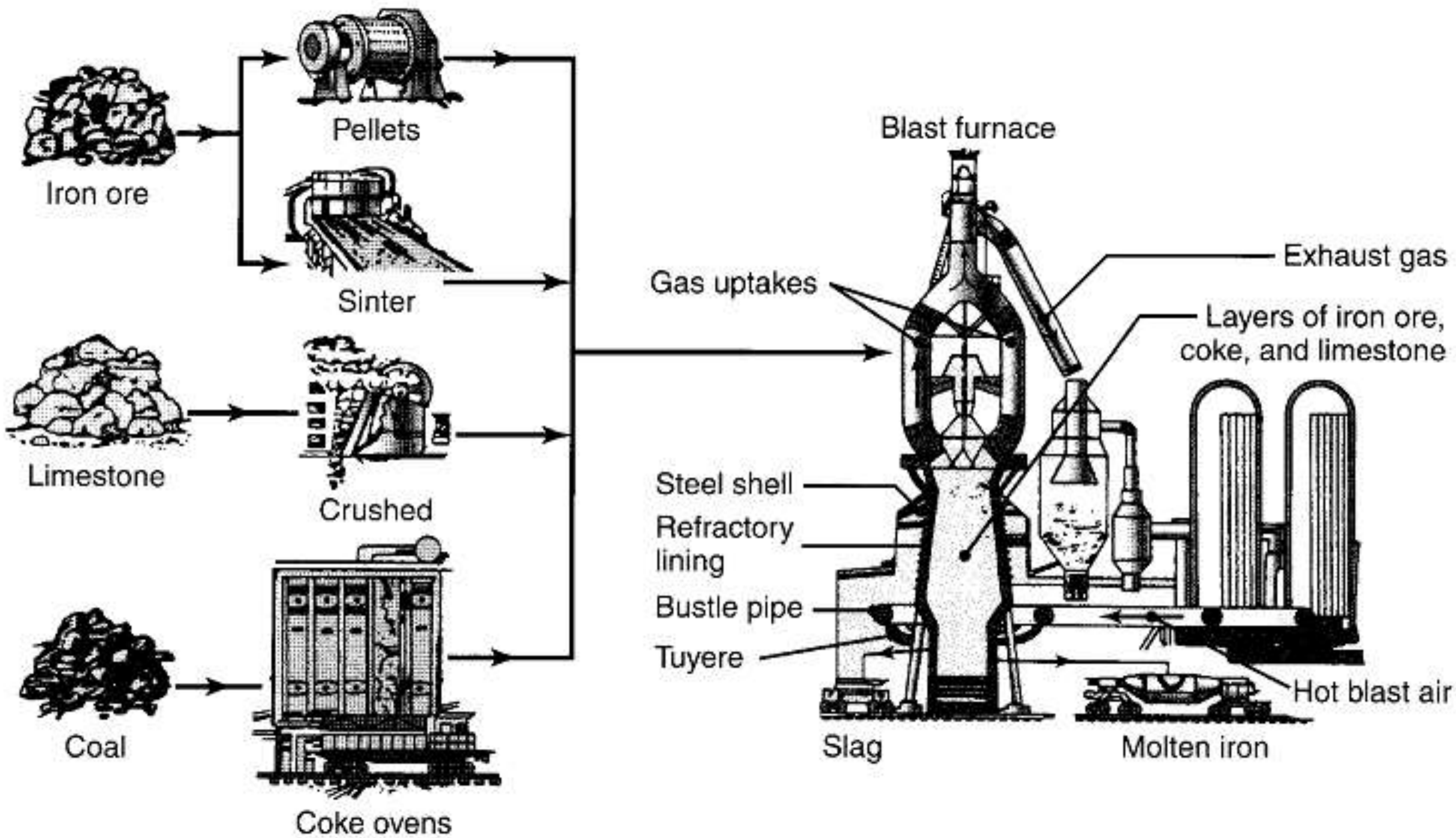
Production of Pig – Iron process

2. Pig iron production



Blast Furnace

Production of Pig – Iron process



Production of Pig – Iron process

3. Steel production

Furnace

Scrap

Pig - Iron

Converter operation

Change vessel converter

Ladle metallurgy

Production of Pig – Iron process

Continuous casting plant

4. Products

Slabs

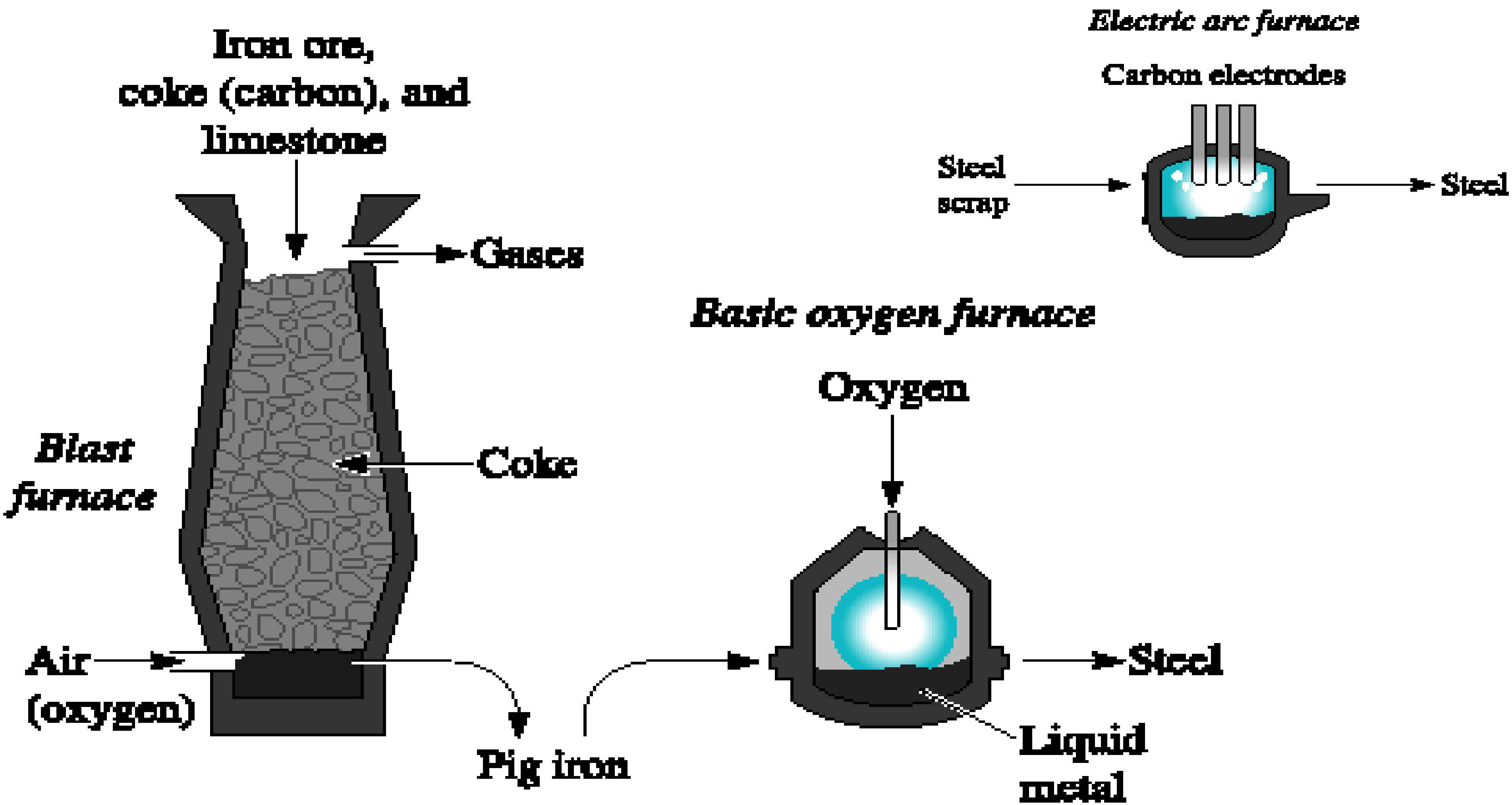
Rounds

By - Products

IRON MAKING -- summary

- Vertical shaft furnace, called a blast furnace
  - Iron ore, coke, and limestone are charged,
  - Hot air (~1200 ^{0}C) is pumped into the bottom of the blast furnace,
  - Limestone attracts impurities, a “slag” forms and floats on top of the molten iron,
  - Iron is drawn off, or “tapped”, and poured into moulds, known as **pig iron**

IRON MAKING -- summary



Iron ore

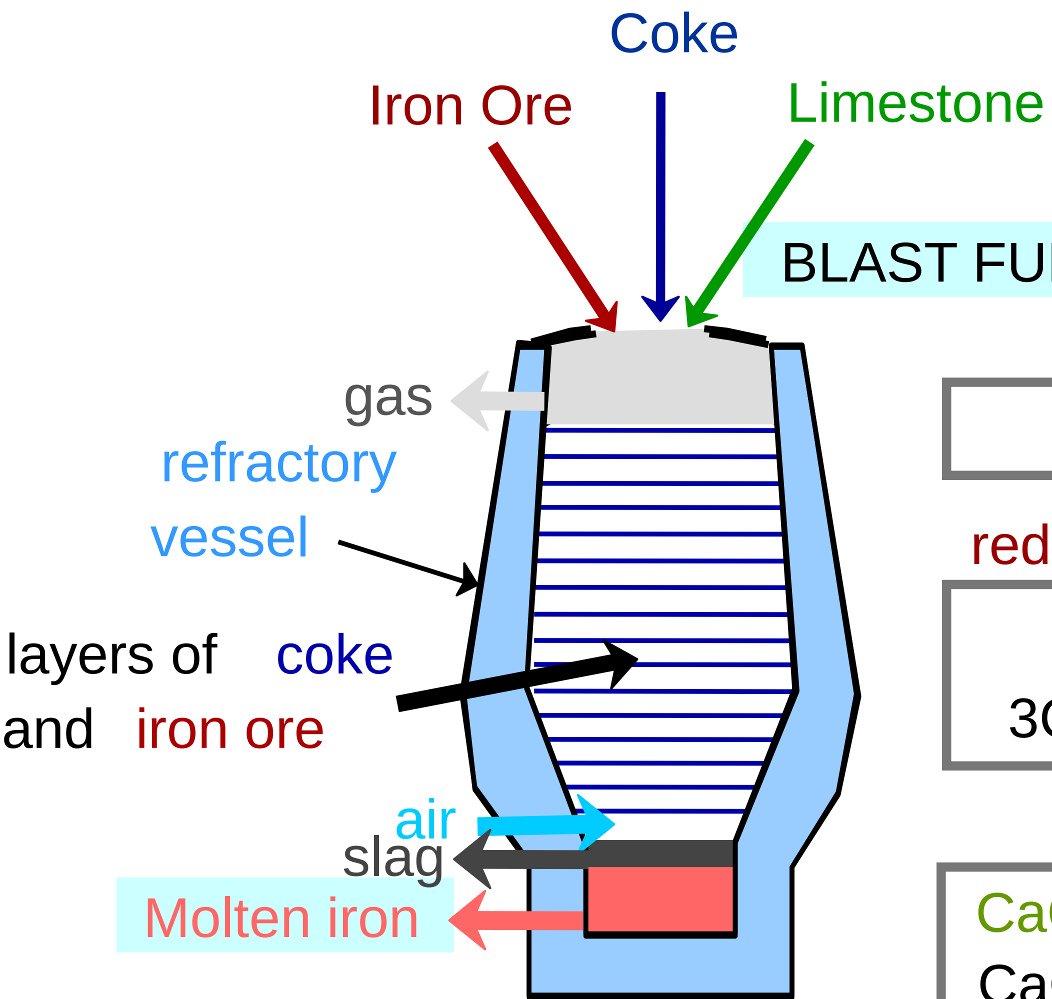
Common iron ores include:

Hematite - Fe_2O_3 - 70 % iron
(a common iron ore)

Magnetite - Fe_3O_4 - 72 % iron
Limonite - $Fe_2O_3 + H_2O$ - 50 % to 66 % iron
Siderite - $FeCO_3$ - 48 percent iron

To create a ton of pig iron, you start with 2 tons of ore, 1 ton of coke and half-ton of limestone. The fire consumes 5 tons of air. The temperature reaches almost 1600 ^{0} C at the core of the blast furnace!

Process: Iron Ore → Steel



heat generation

$$C + O_2 \rightarrow CO_2$$

reduction of iron ore to metal

$$CO_2 + C \rightarrow 2CO$$

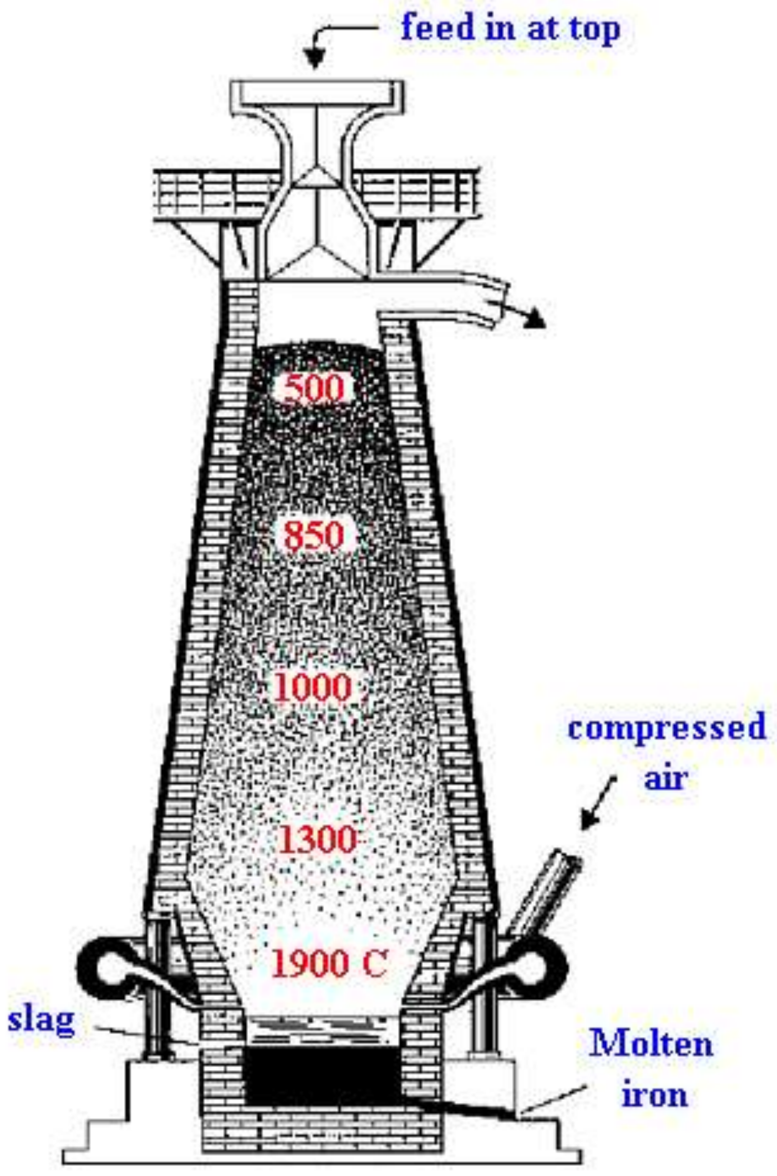
$$3CO + Fe_2O_3 \rightarrow 2Fe + 3CO_2$$

purification

$$CaCO_3 \rightarrow CaO + CO_2$$

$$CaO + SiO_2 + Al_2O_3 \rightarrow slag$$

Extraction of iron in a blast furnace



At 500 °C
$3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2$
$Fe_2O_3 + CO \rightarrow 2FeO + CO_2$

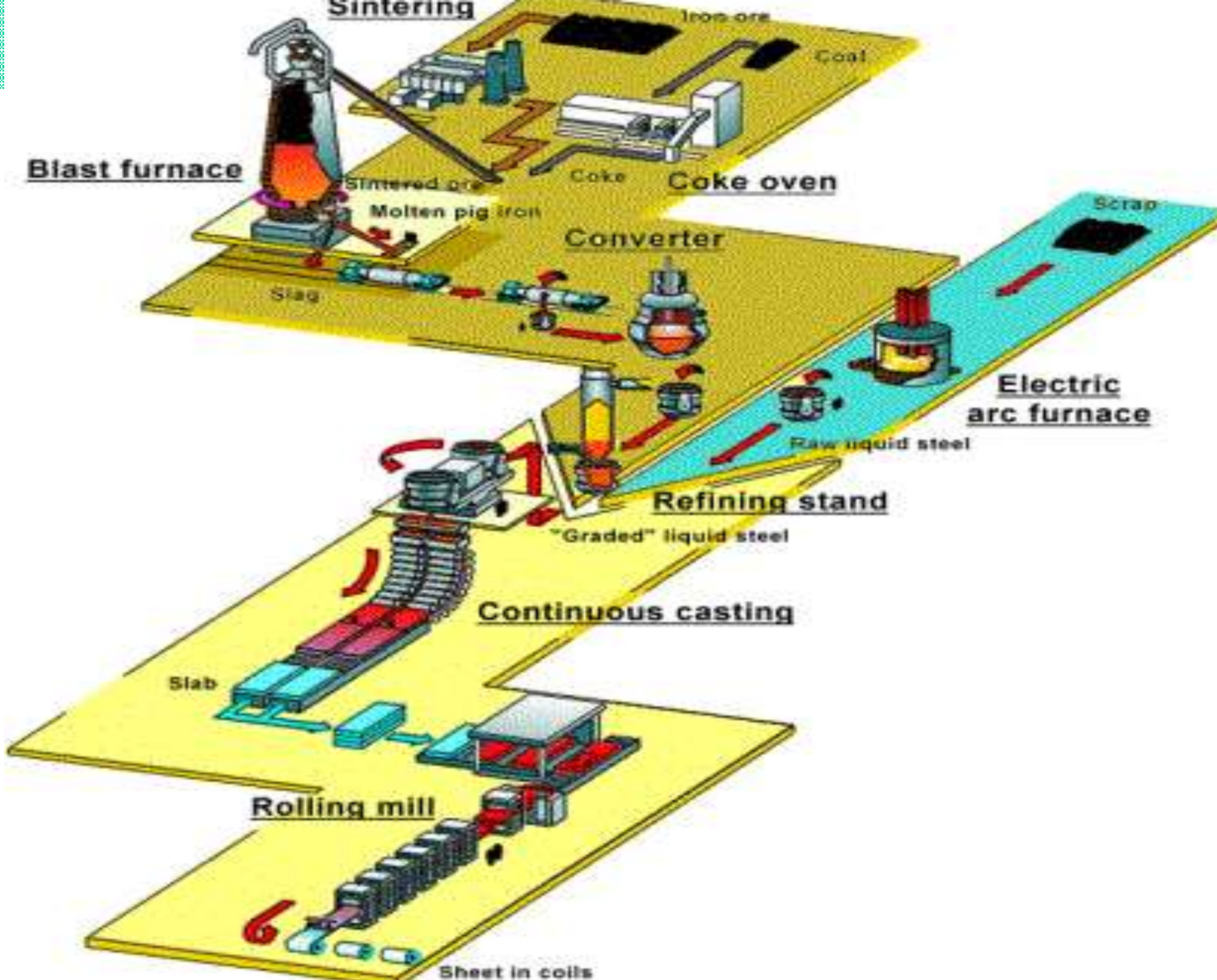
At 850 °C
$Fe_3O_4 + CO \rightarrow 3FeO + CO_2$

At 1000 °C
$FeO + CO \rightarrow Fe + CO_2$

At 1300 °C
$CO_2 + C \rightarrow 2CO$

At 1900 °C
$C + O_2 \rightarrow CO_2$
$FeO + C \rightarrow Fe + CO$

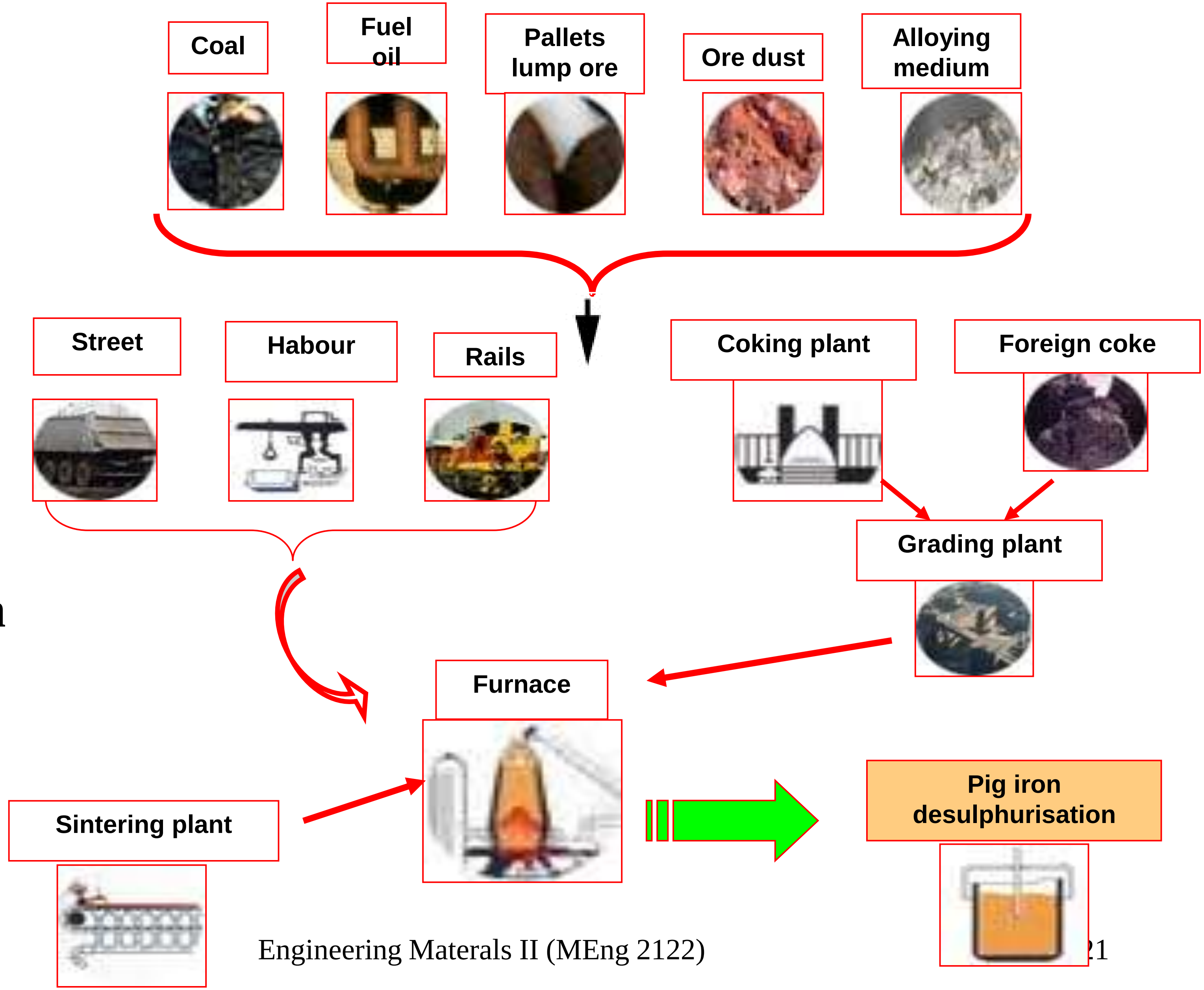
Liquid iron flow in to channel, Pig Iron


Sintering
Iron ore
Coal
Blast furnace
Sintered ore
Coke
Coke oven
Molten pig iron
Converter
Scrap
Slag
Electric
arc furnace
Raw liquid steel
Refining stand
"Graded" liquid steel
Continuous casting
Slab
Rolling mill
Sheet in coils

Introduction - Production of Iron & Steel

Raw materials

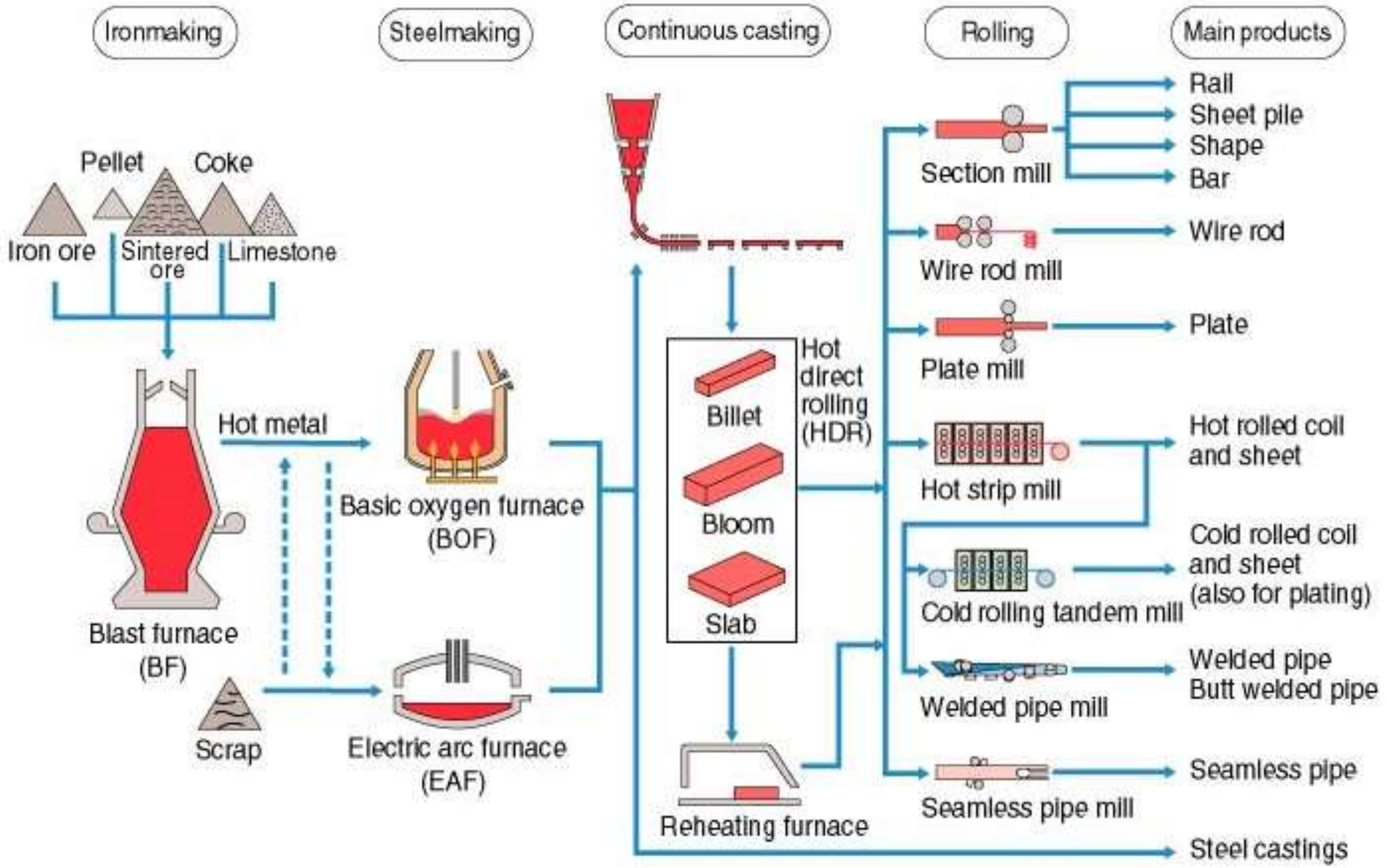
Pig – Iron Production



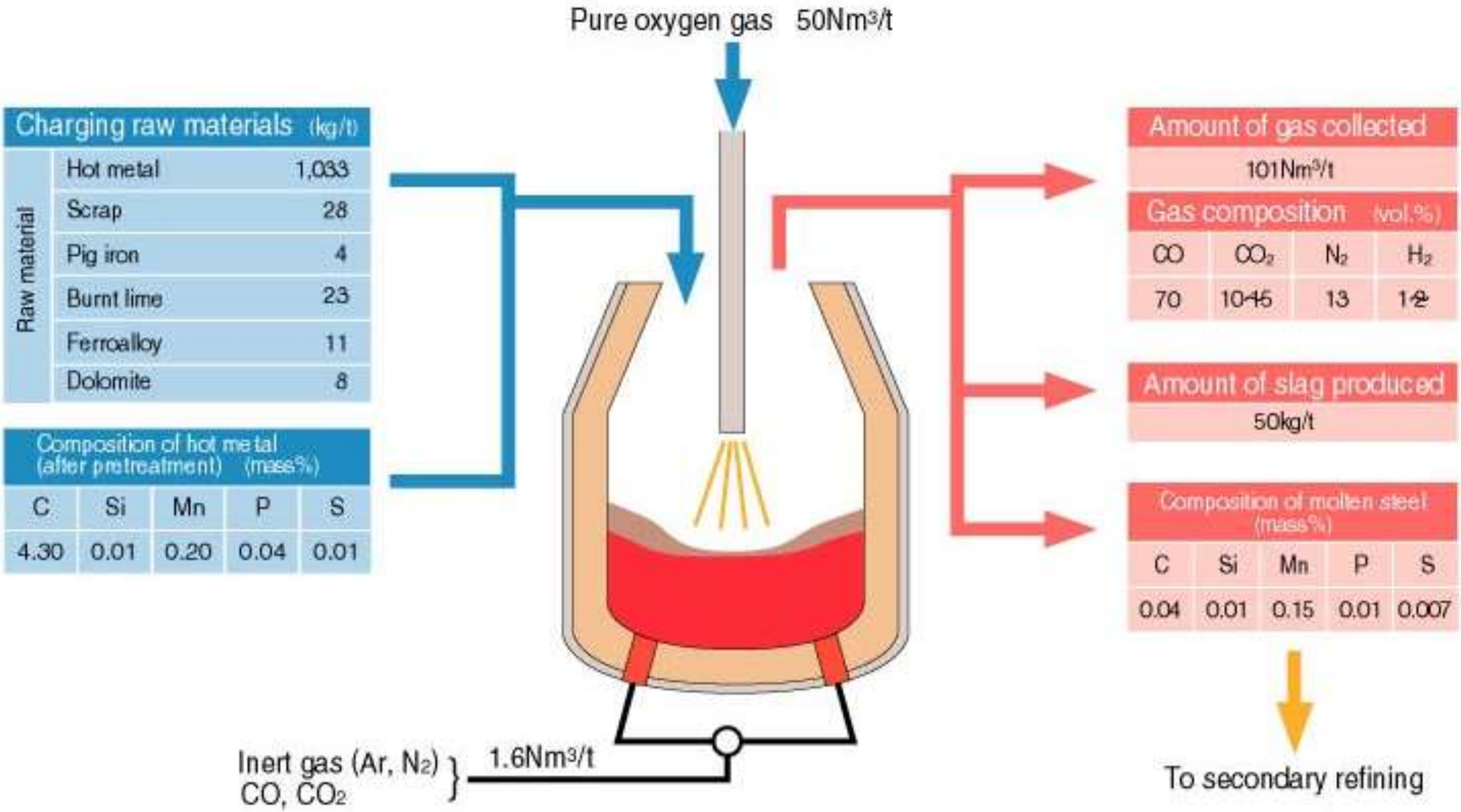
Introduction - Production of Iron & Steel

- ✓ **Steel is essential to everyday life**
  - ✓ **cars, trains, buildings, ships, bridges, refrigerators, medical equipment, for example, are all made with steel.**
- ✓ **Raw Materials - A blast furnace**
  - ✓ **Uses iron ore, coke (made from specialist coking coals) and small quantities of limestone (iron ore, coke and fluxes).**

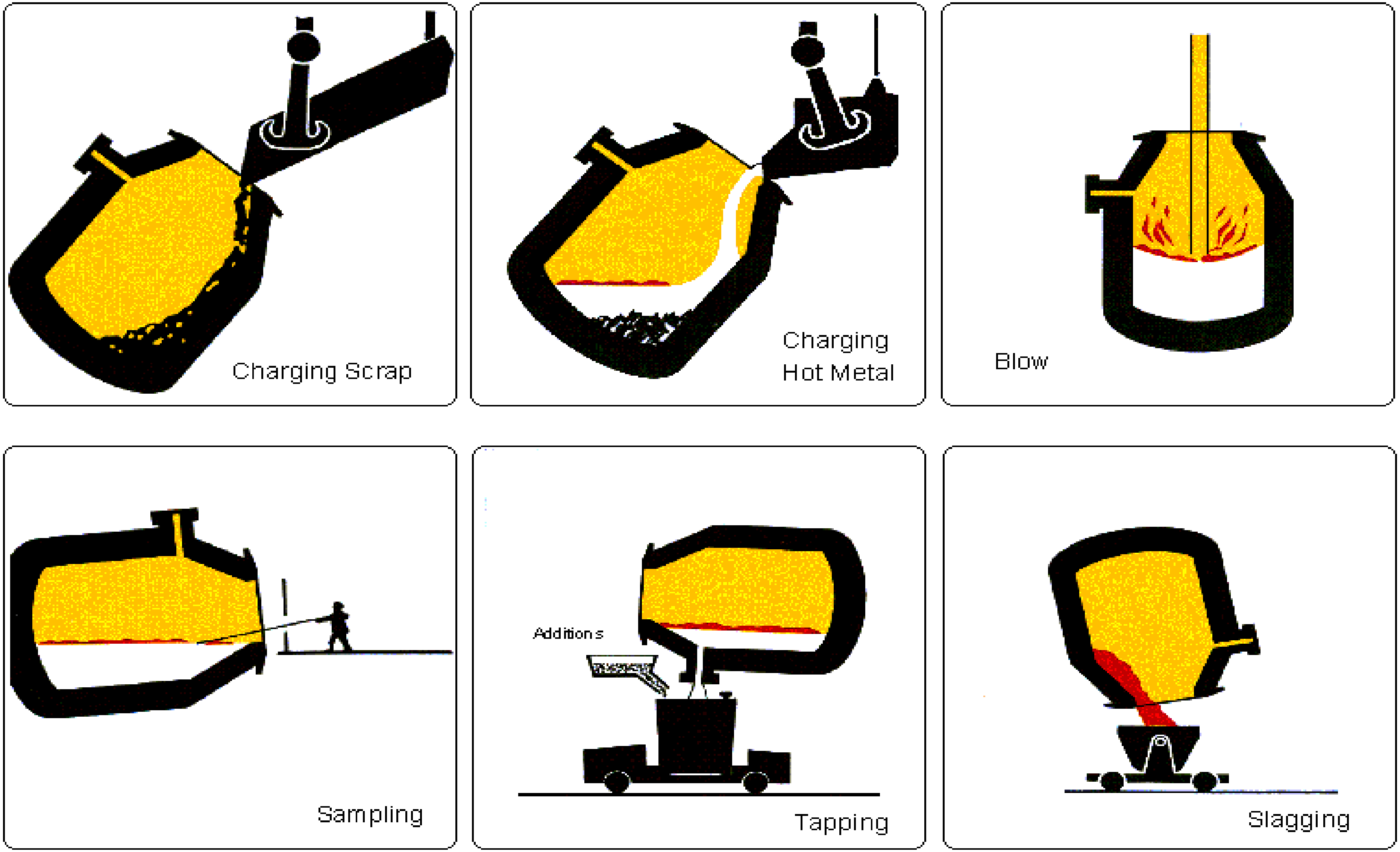
Manufacturing process for iron and steel



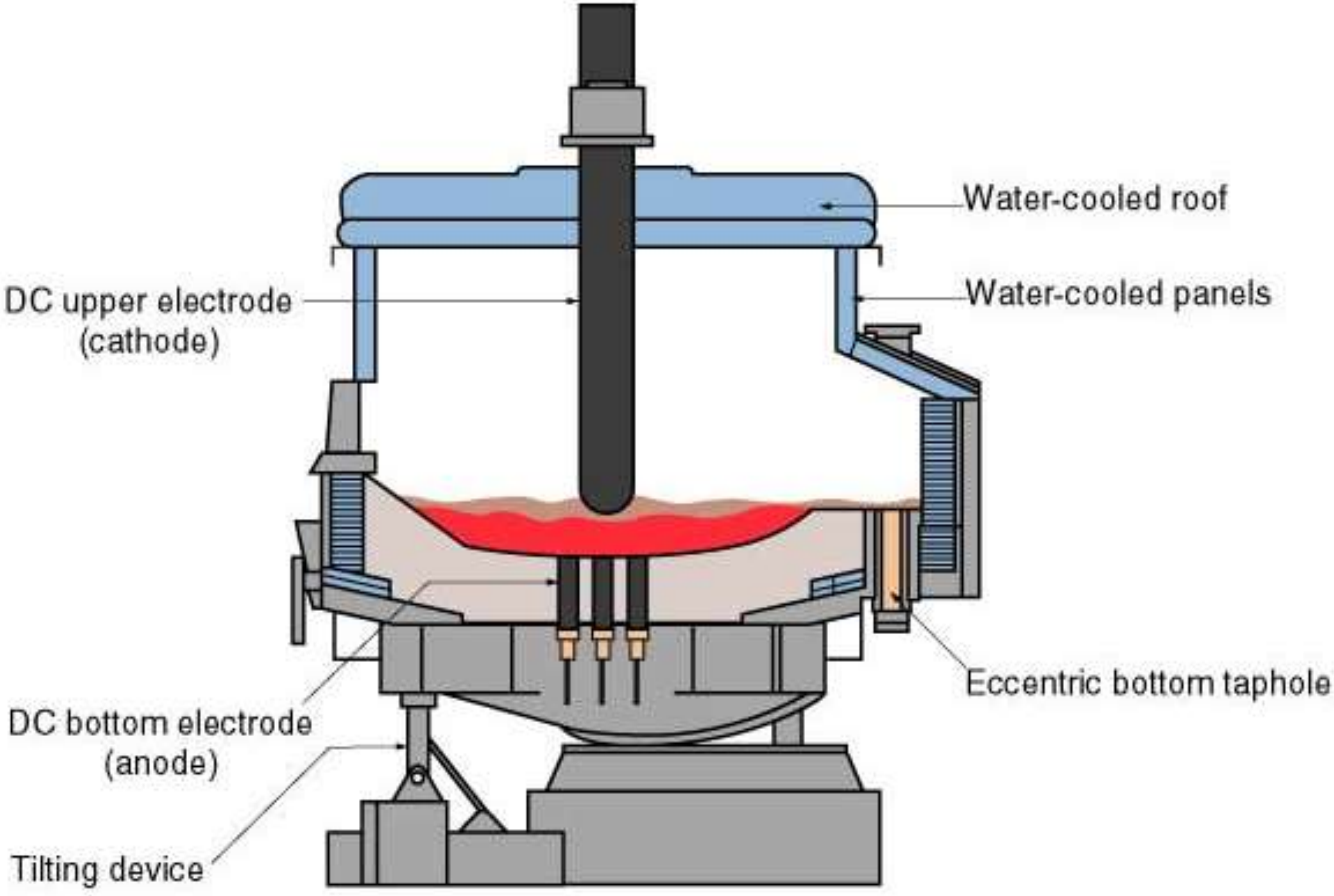
Steel Production Process- BOF



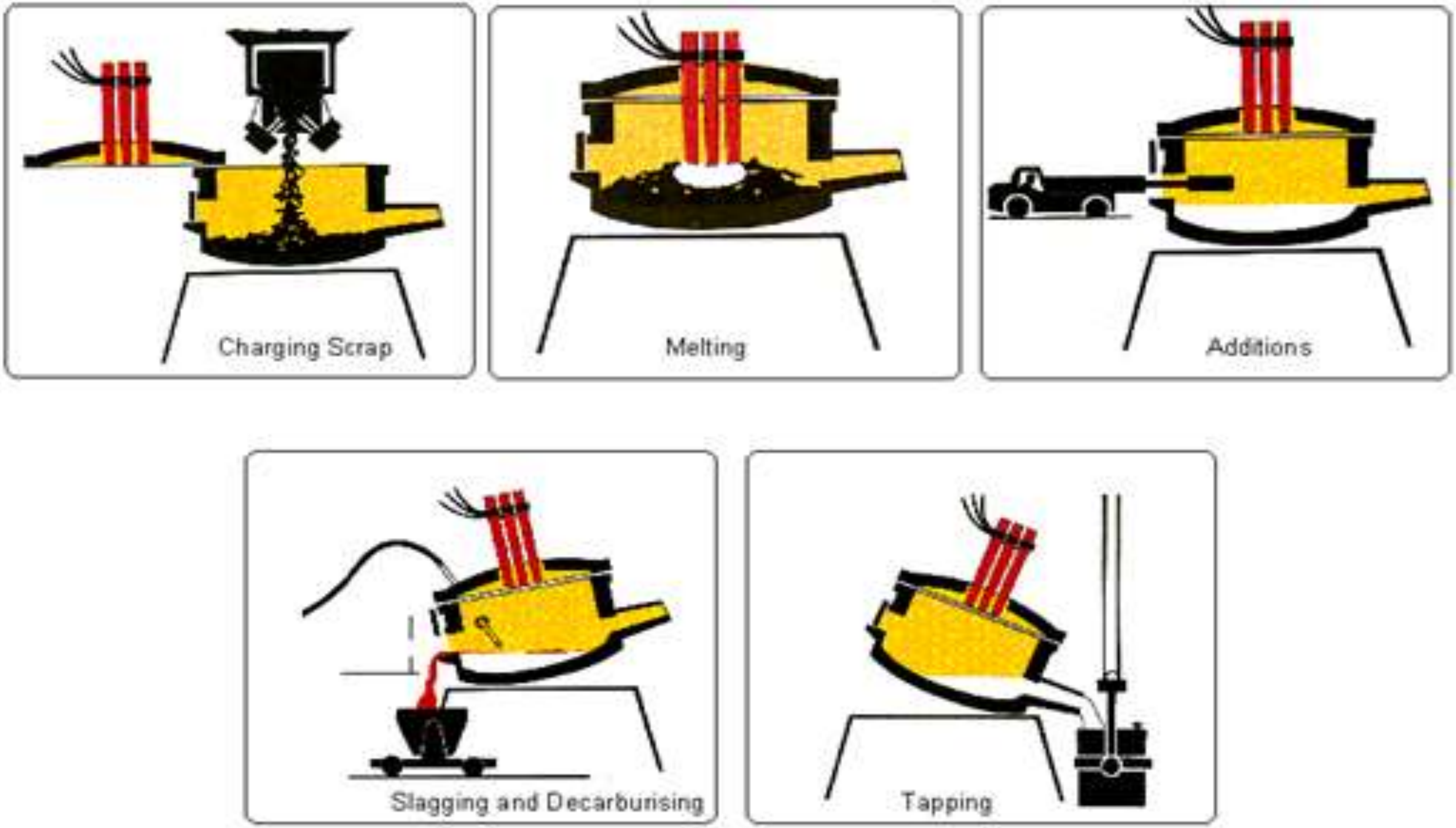
Basic-oxygen Furnace



Steel Production Process- EAF



Electric Furnace



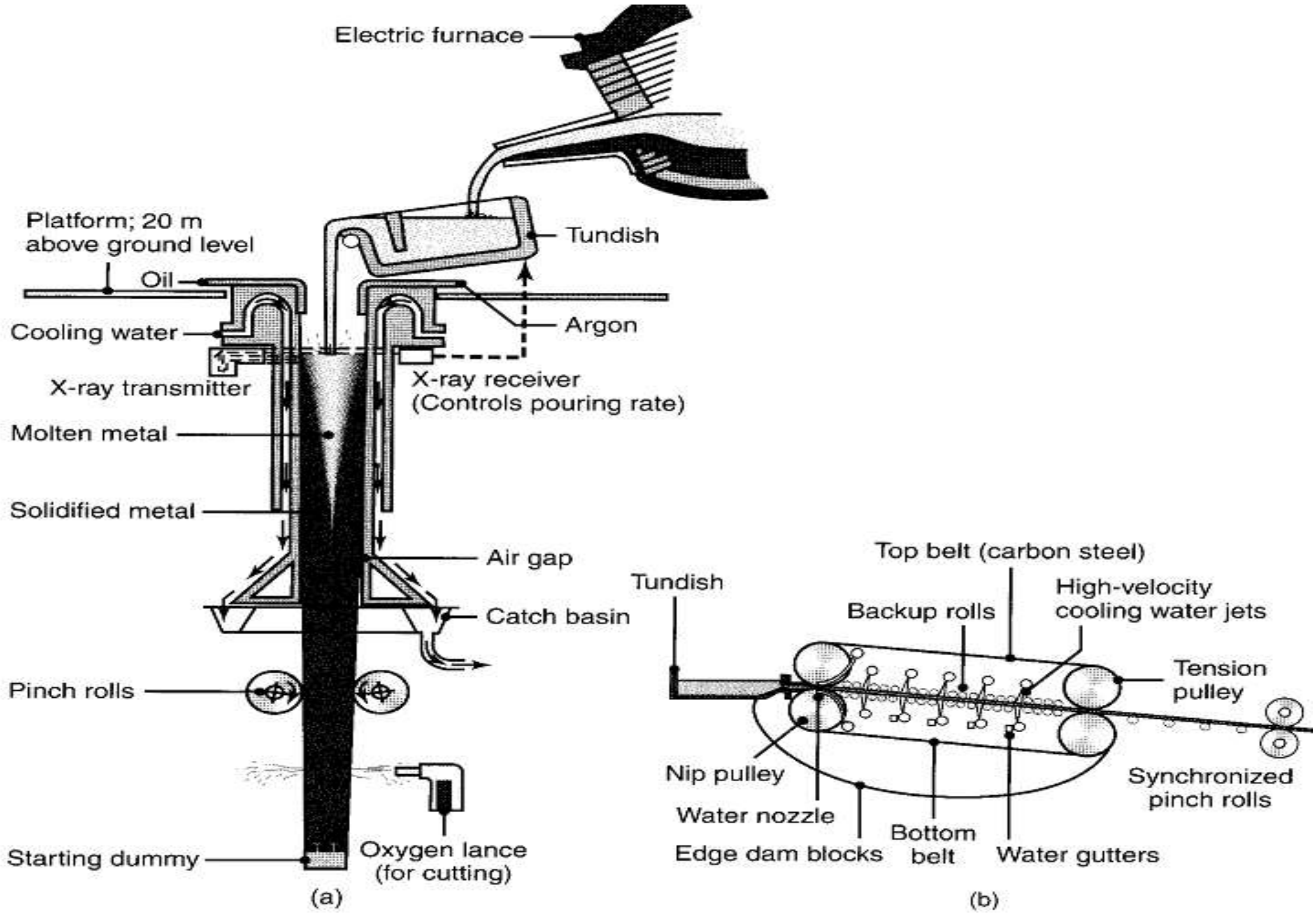
Casting of Ingots

- Traditionally, the next step in the steelmaking process is the shaping of the molten steel into a solid form (**ingot**) for such further processing as rolling, casting, or forging.
- Reactions which takes place during the solidification of an ingot,
  - Significant amounts of **oxygen** and other gases can **dissolve** in the **molten metal** during steel-making. Most of these gases are rejected during the solidification of the metal, because the solubility limit of the gases in the metal decreases sharply as its temperature decreases.
  - Rejected oxygen combines with carbon to form carbon monoxide, which causes ***porosity in the solidified ingot***.
  - Depending on the amount of gas evolved during solidification hree types of steel ingots can be produced: **killed, semi-killed,** and **rimmed**.

Continuous Casting

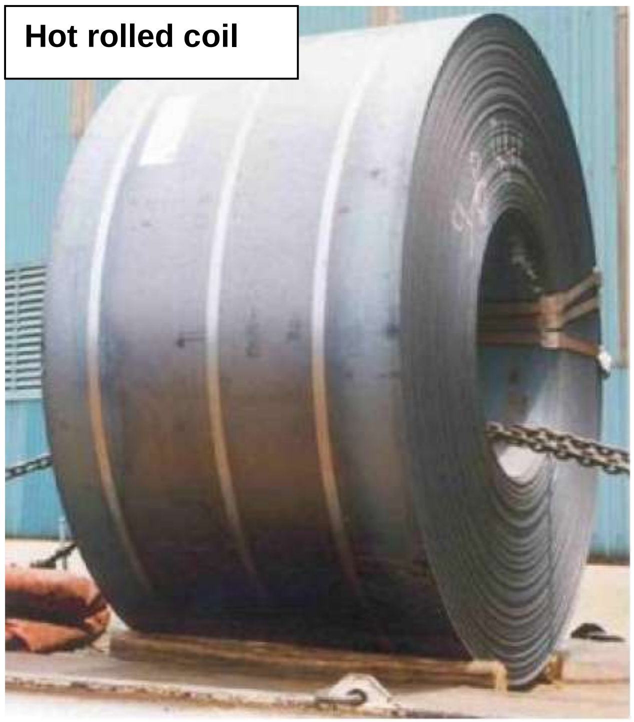
- The inefficiencies and the problems involved in making steels in the traditional form of ingots are alleviated by the continuous-casting process, which produces higher quality steels at reduced costs
- In addition to costing less, continuously cast metals have more uniform compositions and properties than those obtained by ingot casting.
- The continuously cast metal may be cut into desired lengths by shearing or computer-controlled torch cutting, or
- it may be fed directly into a rolling mill for further reduction in thickness and for the shaping of products such as channels and I-beams.

Continuous Casting....




Steel Slabs

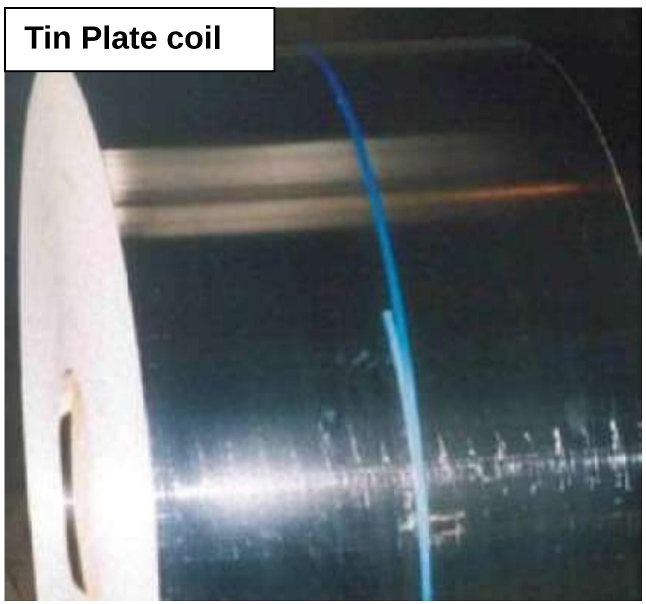

Hot rolled plate


Hot rolled coil

Cold rolled coil

Hot Dipped Galvanized Coil

Electro Galvanized Coil



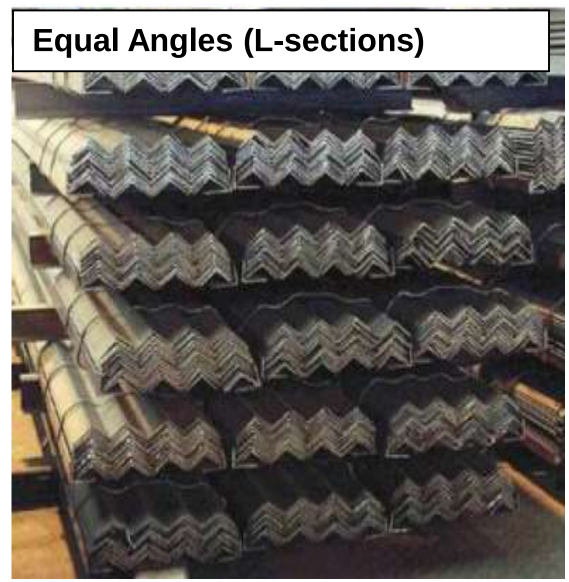
Tin Plate coil

Blooms containing by mass 0,25% or more of carbon


Billets


Reinforcing bar in coils


Wire-rod in coils

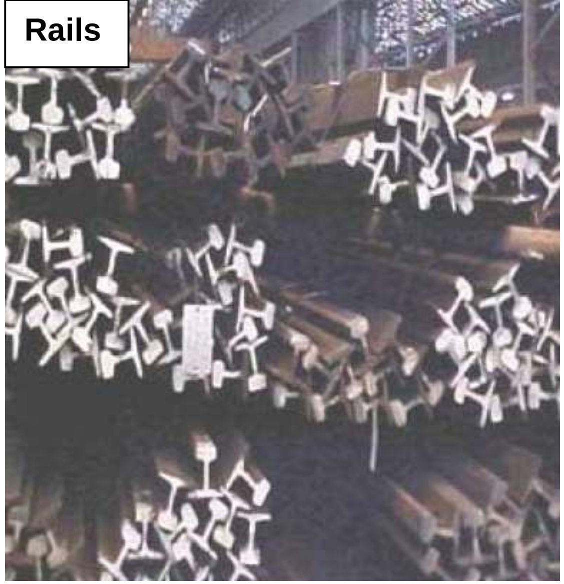

Equal Angles (L-sections)

Sections (I-Beams)

Channels

Rounds (Round bar)

Flat Bar


Rails


Seamless Pipe


Welded Galvanized Steel Pipe

Steel - Introduction

Steels can be classified by a variety of different systems depending on:

- **The composition,**
  - **such as carbon, low-alloy or stainless steel.**
- **The manufacturing methods,**
  - **such as open hearth, basic oxygen process, or electric furnace methods.**
- **The finishing method,**
  - **such as hot rolling or cold rolling**
- **The product form,**
  - **such as bar plate, sheet, strip, tubing or structural shape**

Steel – Introduction ….. Contd.

- The deoxidation practice,
  - such as killed, semi-killed – capped, and rimmed steel
- The microstructure,
  - such as ferritic, pearlitic and martensitic
- The required strength level,
  - as specified in ASTM standards
- The heat treatment,
  - such as annealing, quenching and tempering, and thermomechanical processing
- Quality descriptors,
  - such as forging quality and commercial quality

Carbon Steel

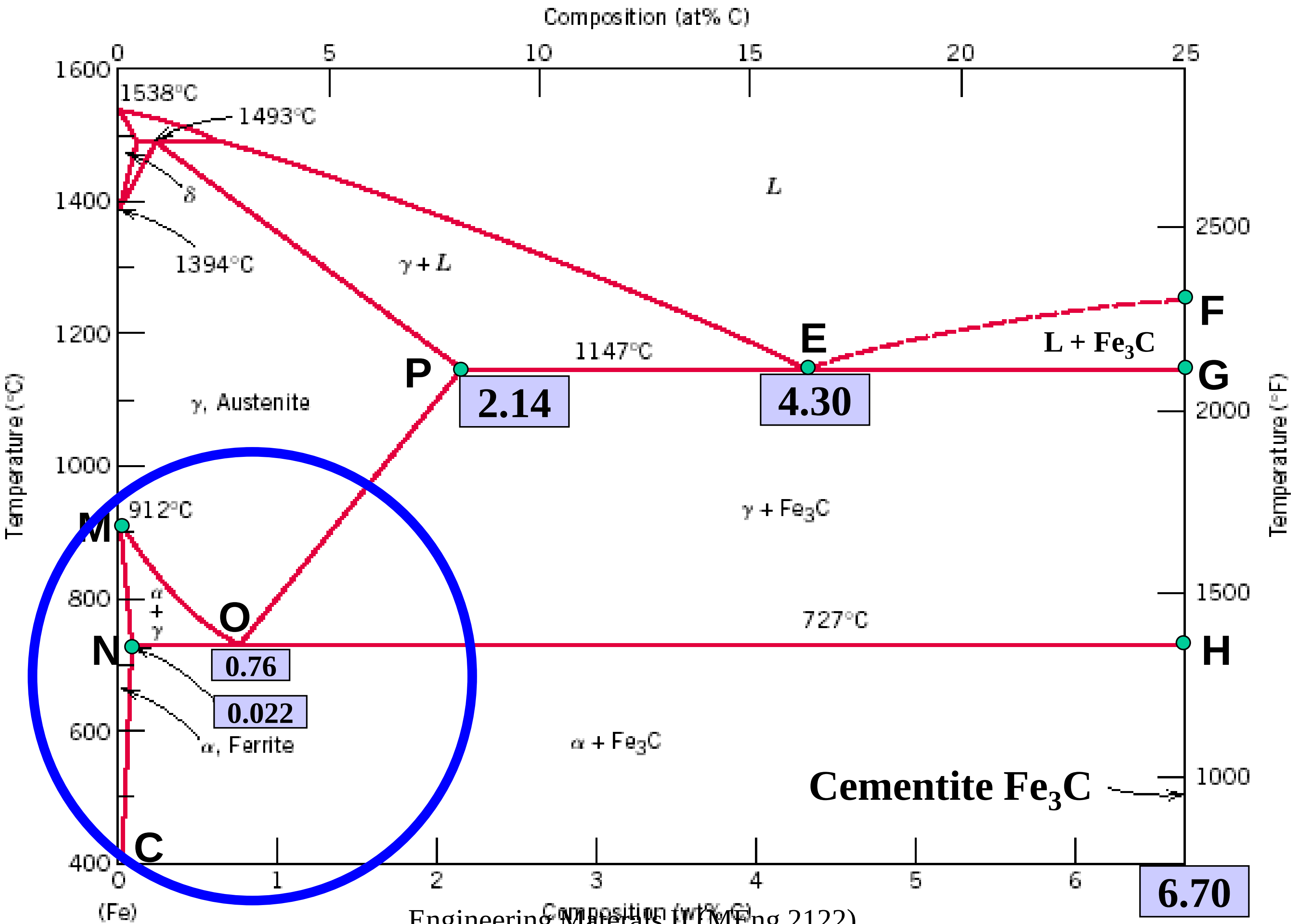
- **The American Iron and Steel Institute (AISI) defines carbon steel as follows:**
  - **Steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, columbium [niobium], molybdenum, nickel, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect.**

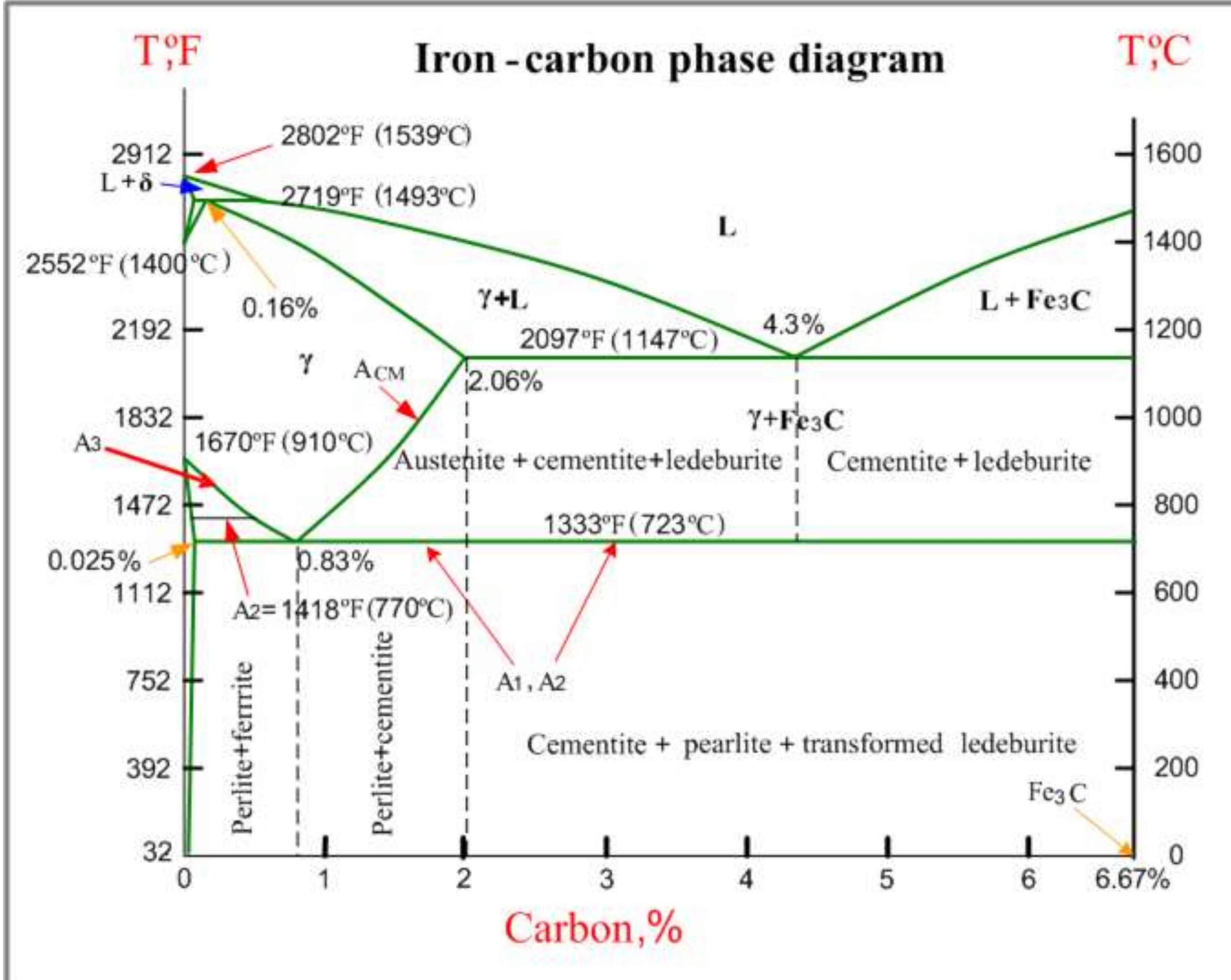
Carbon steels

- Steels whose alloying elements do not exceed the following limits:

Element	Max weight %
C	1.00 (2%)
Cu	0.60
Mn	1.65
P	0.40
Si	0.60
S	0.05

The Iron–Iron Carbide Phase Diagram

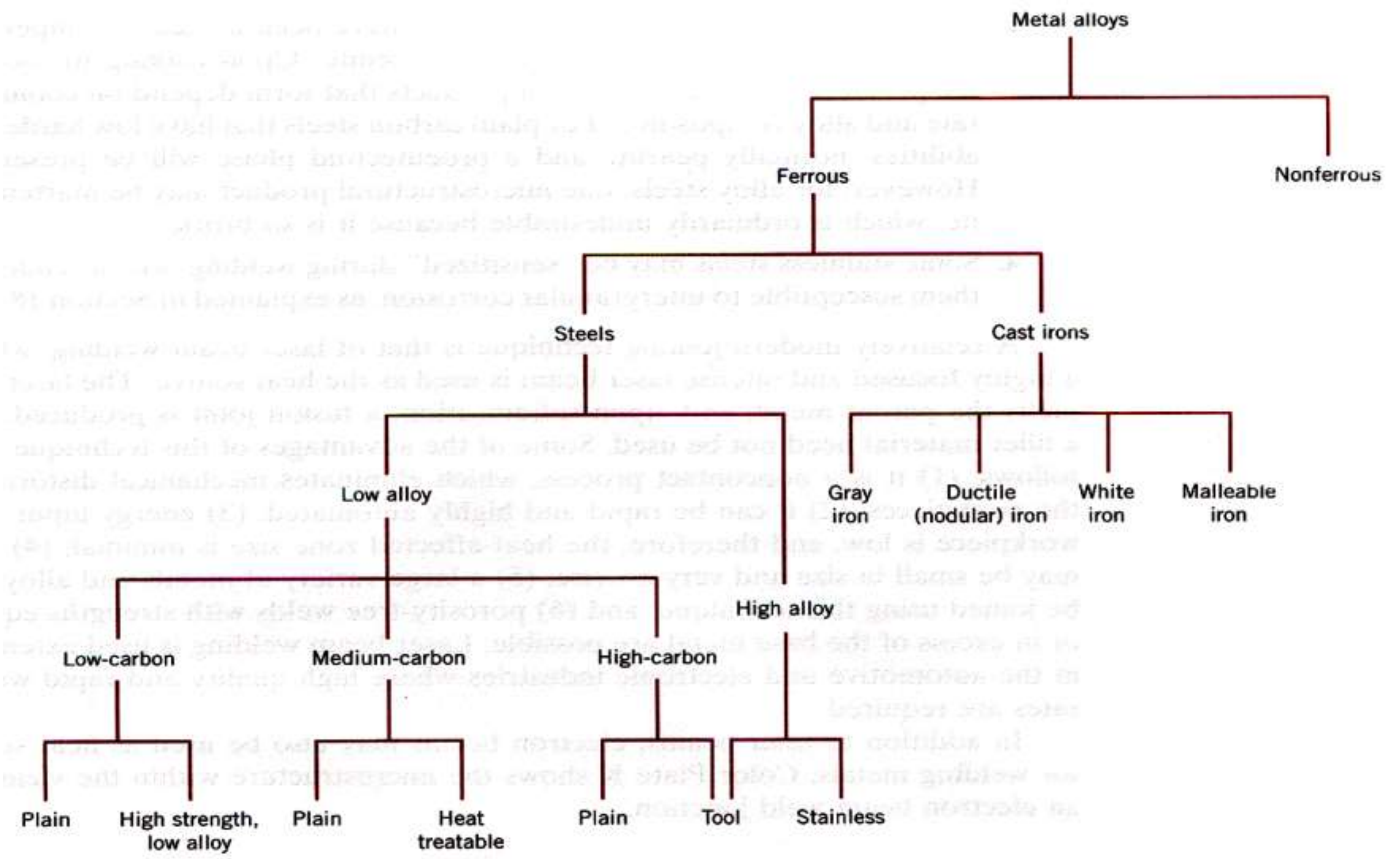



T,°F
Iron - carbon phase diagram
T,°C
2802°F (1539°C)
2912
L + δ
2719°F (1493°C)
L
2552°F (1400°C)
0.16%
γ+L
L + Fe3C
4.3%
2192
2097°F (1147°C)
γ
ACM
2.06%
1832
γ+Fe3C
A3
1670°F (910°C)
Austenite + cementite+ledeburite
Cementite + ledeburite
1472
1333°F (723°C)
0.025%
0.83%
1112
A2= 1418°F (770°C)
752
Perlite+ferrite
Perlite+cementite
A1, A2
392
Cementite + pearlite + transformed ledeburite
Fe3 C
32
0
1
2
3
4
5
6
6.67%
1600
1400
1200
1000
800
600
400
200
0
Carbon,%

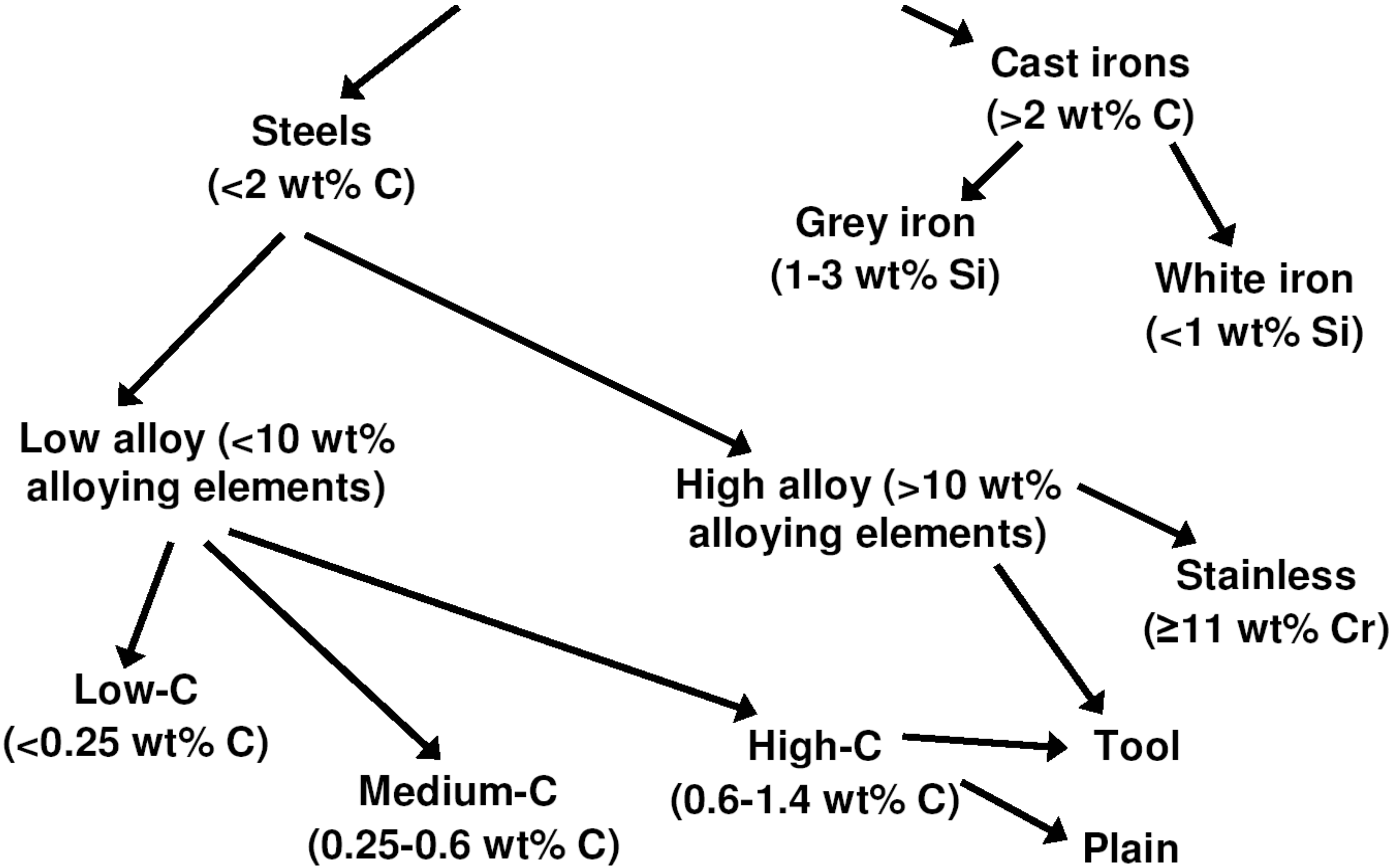
Carbon steels

- Effects of carbon in the **carbon steel**,
  - increased hardness
  - increased strength
  - decreased weldability
  - decreased ductility
  - Machinability **- about 0.2 to 0.25% C provides the best machinability**

Classification scheme for ferrous alloys



Classification of ferrous alloys



STEELS

Low Alloy | **High Alloy**

low carbon <0.25wt%C	med carbon 0.25-0.6wt%C	high carbon 0.6-1.4wt%C

Name	plain	HSLA	plain	heat treatable	plain	tool	austentitic stainless
Additions	none	Cr,V Ni, Mo	none	Cr, Ni Mo	none	Cr, V, Mo, W	Cr, Ni, Mo
Example	1010	4310	1040	43 40	1095	4190	304
Hardenability	0	+	+	++	++	+++	0
TS	-	0	+	++	+	++	0
EL	+	+	0	-	-	--	++
Uses	auto struc. sheet	bridges towers press. vessels	crank shafts bolts hammers blades	pistons gears wear applic.	wear applic.	drills saws dies	high T applic. turbines furnaces V. corros. resistant

increasing strength, cost, decreasing ductility

Carbon steel

- increasing carbon content leading to,
  - increased hardness and strength
  - increases brittleness and reduces weldability .
- Carbon steels (Max 2% C) are generally categorized according to their carbon content.
  - **low-carbon steels (< 0,30 % C)**
  - **medium-carbon steels (0,30% – 0,45% C)**
  - **high-carbon steels(0,45% - 0,75% C)**
  - **ultrahigh-carbon steels (Up to 1,5 % C)**

Classification of carbon steel-Designation system:

- American Iron and Steel Institute (AISI) together with Society of Automotive Engineers (SAE) have established four-digit (with additional letter prefixes) designation system:
    - **SAE 1XXX**
- **First digit** 1 indicates carbon steel (2-9 are used for alloy steels);
- **Second digit** indicates modification of the steel.
    - **0 - Plain carbon, non-modified**
    - **1 - Resulfurized**
    - **2 - Resulfurized and rephosphorized**
    - **5 - Non-resulfurized, Mn over 1.0%**
- **Last two digits** indicate carbon concentration in **0.01%.**

Designation system - modification of the steel

		XX	:0.xx% average carbon content
		↑	
AISI	10	60	
	↓		
	10	:Nonresulfurized grades	
	11	:Resulfurized grades	
	12	:Resulfurized and rephosphorized grades	
	15	:Nonsulfurized grades; max Mn content > 1%	

Classification of carbon steel-Designation system:

- A letter prefix before the four-digit number indicates the steel making technology:
  - A - Alloy, basic open hearth
  - B - Carbon, acid Bessemer
  - C - Carbon, basic open hearth
  - D - Carbon, acid open hearth
  - E - Electric furnace

Example:Designation system SAE 1040 ?

SAE 10<u>40</u>

Carbon content(0.40 %)

Modification in alloy(none) : plain carbon

Indicates whether is a carbon steel or alloy steel (1 indicates carbon steel, 2 and above indicates alloy steel)

Example:Designation system:

- SAE 1030
  - means non modified carbon steel(Plain carbon),
  - containing 0.30% of carbon.

- AISI B1020
  - means non-modified carbon steel,
  - produced in acid Bessemer and
  - containing 0.20% of carbon